



Tech Briefs

National Aeronautics and
Space Administration



Electronic Components and Circuits



Electronic Systems



Physical Sciences



Materials



Computer Programs



Mechanics



Machinery



Fabrication Technology



Mathematics and Information Sciences



Life Sciences

COMPLETED

INTRODUCTION

Tech Briefs are short announcements of new technology derived from the research and development activities of the National Aeronautics and Space Administration. These Briefs emphasize information considered likely to be transferable across industrial, regional, or disciplinary lines and are issued to encourage commercial application.

Availability of NASA Tech Briefs and TSP's

Distribution of NASA Tech Briefs, a monthly periodical publication, is limited to engineers in U.S. industry and to other domestic technology transfer agents. Requests for individual Tech Briefs or for Technical Support Packages (TSP's) announced herein should be addressed to

NASA Center for AeroSpace Information
Technology Transfer Office
800 Elkridge Landing Rd.
Linthicum Heights, MD 21090-2934
Telephone No. (301) 621-0245

Please reference the three-letter, five-digit control number located at the end of each Tech Brief. Information on NASA's Technology Utilization Program, its documents, and services is also available at the same facility.

Technology Utilization Officers and Patent Counsels are located at NASA field installations to provide technology-transfer access to industrial users. Inquiries can be made by writing to NASA field installations listed below.

Technology Utilization Officers and Patent Counsels

Ames Research Center
Technology Utilization Officer
Mail Code 223-3
Moffett Field, CA 94035

Patent Counsel
Mail Code 200-11
Moffett Field, CA 94035

Goddard Space Flight Center
Technology Utilization Officer
Mail Code 702-1
Greenbelt, MD 20771

Patent Counsel
Mail Code 204
Greenbelt, MD 20771

Lyndon B. Johnson Space Center
Technology Utilization Officer
Mail Code LC-4
Houston, TX 77058

Patent Counsel
Mail Code AL3
Houston, TX 77058

John F. Kennedy Space Center
Technology Utilization Officer
Mail Stop PT-PMO-A
Kennedy Space Center, FL 32899

Patent Counsel
Mail Code PT-PAT
Kennedy Space Center, FL 32899

Langley Research Center
Technology Utilization Officer
Mail Stop 143
Hampton, VA 23665

Patent Counsel
Mail Code 279
Hampton, VA 23665

Lewis Research Center
Technology Utilization Officer
Mail Stop 7-3
21000 Brookpark Road
Cleveland, OH 44135

Patent Counsel
Mail Code LE-LAW
21000 Brookpark Road
Cleveland, OH 44135

Jet Propulsion Laboratory
Technology Utilization Officer
Mail Stop 156-211
4800 Oak Grove Drive
Pasadena, CA 91108

NASA Resident Office-JPL
Technology Utilization Officer
Mail Stop 180-801
4800 Oak Grove Drive
Pasadena, CA 91109

Patent Counsel
Mail Code 180-801
4800 Oak Grove Drive
Pasadena, CA 91109

George C. Marshall Space Flight Center
Technology Utilization Officer
Code AT01
Marshall Space Flight Center,
AL 35812

Patent Counsel
Mail Code CC01
Marshall Space Flight Center,
AL 35812

John C. Stennis Space Center
Technology Utilization Officer
Code HA-30
Stennis Space Center, MS 39529

NASA Headquarters
Technology Utilization Officer
Code CU
Washington, DC 20546

Assistant General
Counsel for Patent Matters
Code GP
Washington, DC 20546

Dryden Flight Research Center
Technology Utilization Officer
M/S D21-31
Bldg. 4832 Whse 7
Lilly Dr.
Edwards, CA 93523

BLANK PAGE



5	Electronic Components and Circuits	
----------	---	---

9	Electronic Systems	
----------	---------------------------	---

13	Physical Sciences	
-----------	--------------------------	---

21	Materials	
-----------	------------------	---

25	Computer Programs	
-----------	--------------------------	---

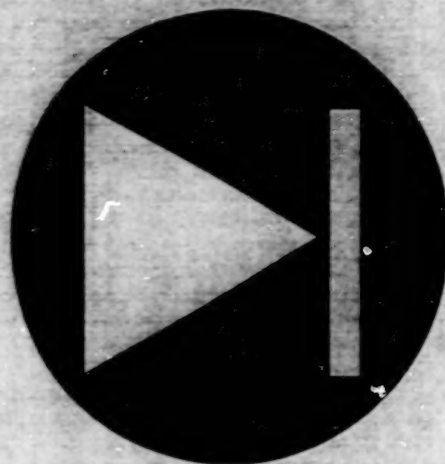
29	Mechanics	
-----------	------------------	---

33	Machinery	
-----------	------------------	---

39	Fabrication Technology	
-----------	-------------------------------	---

47	Mathematics and Information Sciences	
-----------	---	---

This document was prepared under the sponsorship of the National Aeronautics and Space Administration. Neither the United States Government nor any person acting on behalf of the United States Government assumes any liability resulting from the use of the information contained in this document, or warrants that such use will be free from privately owned rights.



Electronic Components and Circuits

Hardware, Techniques, and Processes

- 7 Rechargeable Microbatteries With Li Anodes Formed In Situ
- 8 Lightweight Dual-Beam Reflector Antenna

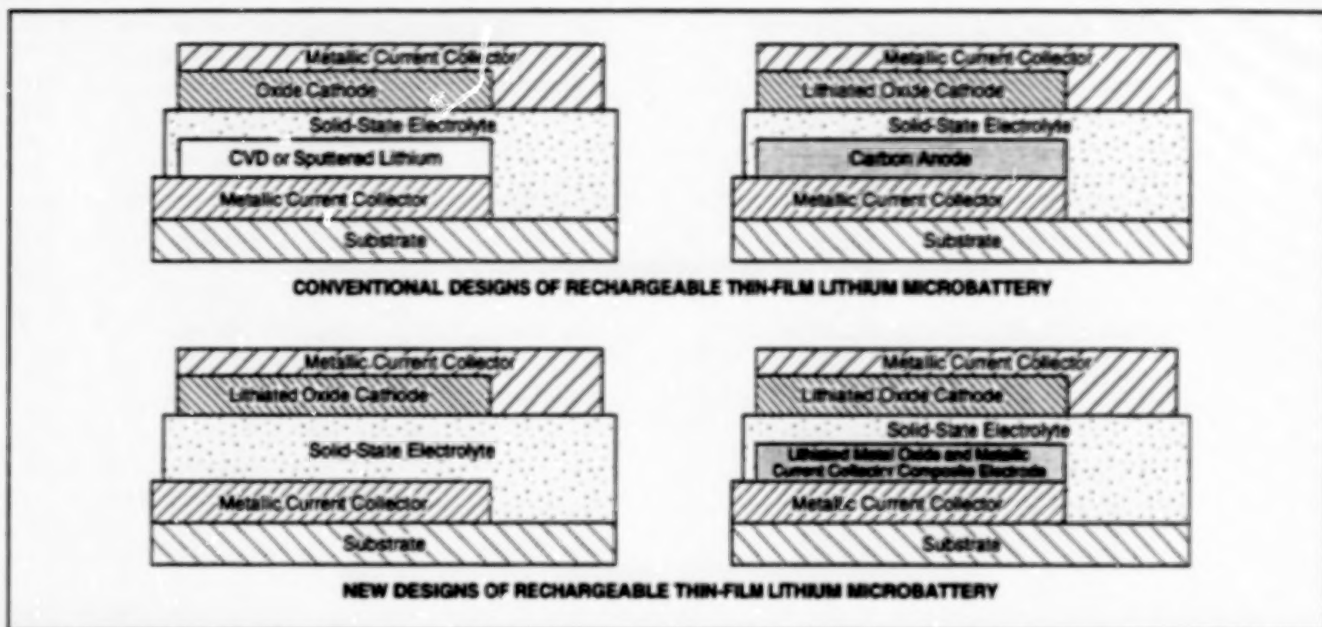
6

BLANK PAGE

Rechargeable Microbatteries With Li Anodes Formed In Situ

These batteries would offer advantages with respect to safety and manufacturability.

NASA's Jet Propulsion Laboratory,
Pasadena, California



The Lithiated Oxide Cathodes in the proposed cells would contain the usable lithium at the time of fabrication; metallic lithium would not be present at the time of fabrication as it is in state-of-the-art cells.

Rechargeable, thin-film, lithium-based microbatteries of the proposed type would be manufactured in the discharged condition, and lithium anodes would be formed in situ during subsequent charging. In contrast, state-of-the-art rechargeable, thin-film, lithium-based microbatteries are fabricated in the charged condition, with metallic lithium anodes. As explained below, the proposed batteries would offer advantages of safety and manufacturability over the state-of-the-art batteries.

Rechargeable, thin-film, lithium-based microbatteries are potentially useful as power sources on integrated-circuit chips. For example, they could provide standby power for complementary oxide/semiconductor memory chips. The advantages of lithium-based microbatteries over typical power sources include the following:

- They can be fabricated in a variety of shapes;
- Because they are all-solid-state, there is no worry about gaseous components generated during operation;
- They feature high energy and power densities; and
- They can endure large numbers of charge/discharge cycles.

The figure schematically illustrates the structures of cells in alternative versions of the state-of-the-art and the proposed

rechargeable, thin-film, lithium-based batteries. In fabricating a state-of-the-art battery, the metallic lithium anodes are formed by chemical vapor deposition (CVD) or sputtering of lithium. The cathodes are made of TiS_2 or V_2O_5 . The metallic lithium in the newly formed anodes is very chemically reactive with moisture and air; this poses a danger and can cause loss of usable lithium during later stages of fabrication. The fabrication process is complicated by the requirements of the deposition process and the need to take extreme care for safety and for preservation of the newly deposited lithium.

The difficulty, danger, and complexity by deposition of metallic lithium would not be present in the fabrication of a battery of the proposed type because lithium would not be used in metallic form during the fabrication process. Instead, the usable lithium stock in each cell would be intercalated into a metal oxide to make a cathode of lithiated metal oxide (for example, LiCoO_2 , LiNiO_2 , or LiMn_2O_4). The anode in each cell would be fabricated as either (1) a metallic Cu, Ni, or Ag current-collecting electrode formed by sputtering or CVD; or else (2) an electrode layer of composite material made by mixing a current-collector metal (Cu, Ag, or Ni) with a fully lithiated oxide (e.g., tungsten oxide).

During subsequent charging, lithium ions would be deintercalated from the cathode, and metallic lithium would be plated onto the anode; this plating process would constitute the in situ formation of lithium mentioned above.

The solid electrolyte in the proposed cells could be $\text{Li}_3\text{PO}_4\text{N}_{0.22}$, which is used in the state-of-the-art cells. Alternatively, the solid electrolyte could be Li_5SiP_3 or Li_5SiP_4 . If necessary, the proposed microbatteries could be encapsulated with electrically insulating materials. Another option would be the use of carbon as an anode material, though at the present state of development, it appears that the lithiated metal oxides would offer superior performance.

This work was done by Chen-Kuo Huang and Shiao-Ping Yeh of Caltech and Jeff Wolfenstine of UC Irvine for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 1]. Refer to NPC-19778.

Lightweight Dual-Beam Reflector Antenna

The design addresses some partly overlapping and competing requirements.

The figure illustrates a lightweight composite-material dual-beam reflector antenna for the SeaWinds spaceborne scatterometer instrument, which operates in the K_u band and is designed to measure wind velocities at the surface of the ocean. The design of the antenna could also be of interest for terrestrial applications in that it addresses issues that are not unique to any particular application and that involve some overlap and competition between mechanical and electromagnetic-performance requirements.

The mechanical requirement is that the antenna be stiff enough to resist vibrations to an acceptable degree, as quantified by a vibrational-resonance frequency of at least 94 Hz. The basic electromagnetic-performance requirement is to generate two linearly polarized, independent beams at angles of 40° and 46° from the nadir when the reflector axis is aimed at 43° from the nadir. The inner beam (the one at 40°) must be horizontally polarized and have widths of 1.6° and 1.8° in the azimuth and elevation planes, respectively. The outer beam (the one at 46°) must be vertically polarized and have widths of



This Dual-Beam Reflector Antenna features a lightweight composite-material structure. The aperture is elliptical, with major and minor axes of 1.07 and 0.96 m, respectively. The total mass is only 6.4 kg.

1.4° and 1.7° in the azimuth and elevation planes, respectively. The first sidelobe of each beam is required to be at least 15 dB below the peak of the beam.

The reflector surface is a paraboloid with an elliptical aperture. Two offset feeds (one for each beam) are mounted on a feed-support plate held by struts. To satisfy the stiffness requirement, the struts had

to be made wider and the feed-support plate larger than in an ordinary design for an antenna of this type. It was found that, in the absence of corrective measures, (1) the increase in aperture blockage caused by enlargement of the feed-support plate and (2) interactions between the feed horns and the enlarged feed-support plate would result in sidelobe levels higher than allowed under the performance requirements, lower antenna gain, and altered beam widths.

By a combination of theory and experiment, it was found that suitable corrective measures would include coating the feed-support plate with an absorbing material, extending the inner-beam feed horn, and adding a choke around the outer-beam feed horn. Tests showed that these measures reduced sidelobe to the required levels and afforded some improvements in gain and beam widths.

This work was done by Ziad Hussein, Yahya Rahmat-Samii, and Kent Kellogg of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20161



Electronic Systems

Hardware, Techniques, and Processes

- 11 Optical Horizontal-Displacement Sensors for Crane Payloads
- 11 Sight-to-Touch Translator
- 12 Automated Cable-Analyzer System — ACAS

Optical Horizontal-Displacement Sensors for Crane Payloads

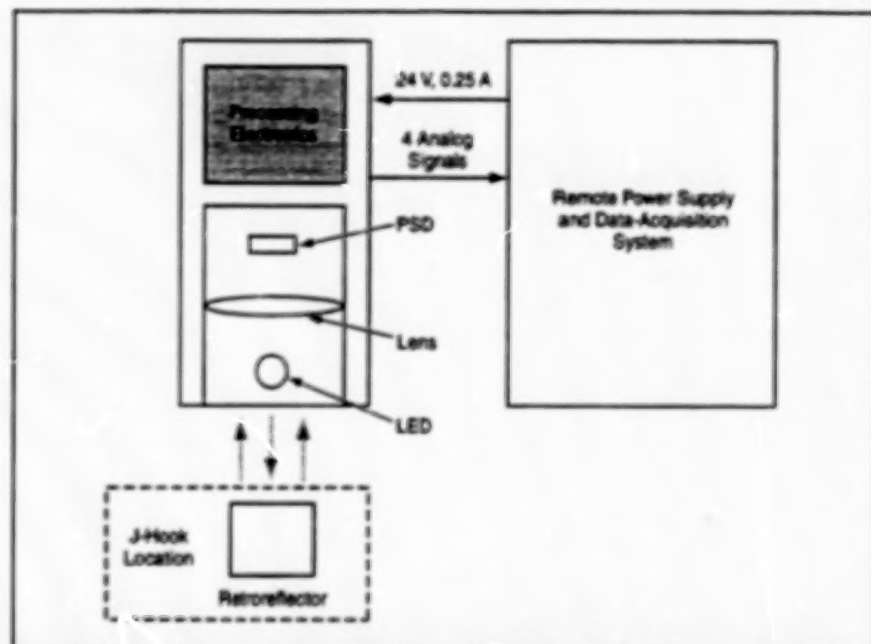
It is not necessary to run wires along the crane cables.

John F. Kennedy Space Center,
Florida

Sensors made largely of commercially available optical and electronic components are being developed for use in measuring small horizontal displacements of payloads suspended below cranes at the ends of nominally vertical cables. The outputs of these sensors would be used in computer-based automated and manual crane-control systems to guide the horizontal movements of the cranes with respect to the payloads or with respect to nearby objects. For example, in the original intended application, the horizontal displacement would be produced by manually pushing a heavy payload in a desired direction, and the output of an optoelectronic sensor that measured this displacement would be sent to a computer-based crane-control system, which would apply power to move the crane in that direction.

A sensor of this type includes a source of a well-defined beam of light (e.g., a diode laser and beam-expanding optics) mounted on the crane at the upper end of the cable, nearby photodetectors off to the sides of the source of light, and a corner-cube reflector mounted on the hook or payload at the lower end of the cable. An important advantage of this sensor concept (see figure) is that it is not necessary to run wires along the cable to supply power to a transducer at the payload end.

A corner-cube reflector is a standard, commercially available retroreflector. It sends light back toward the source along a direction parallel to the direction of incidence, laterally offset by the lateral distance between the point of incidence and the point of final reflection. The lateral offset of the reflected beam equals twice the lateral displacement of the apex of the corner cube from the centerline of the beam of light from the source. When one of the photodetectors intercepts the reflected



In this profile-view schematic diagram of **Crane-Position Sensor**, light is projected toward the retroreflector, which reflects it back to the position-sensitive detector (PSD), monitoring the location of the reflection site.

light, that photodetector responds, signifying that the payload has been laterally displaced from the centerline in the same direction and by half the distance of the photodetector from the centerline.

An alternative approach utilizes a two-dimensional position-sensitive detector (PSD) to produce a set of four analog signals indicative of the lateral location of the retroreflector. PSDs are solid-state silicon photodetectors, which produce multiple currents whose magnitudes are proportional to the location of the centroid of the light impinging upon them. In this second approach, a high-brightness light-emitting diode (LED) is modulated at a few kilohertz and aimed at a retroreflector attached to the J-hook as shown in the figure. The reflected light is imaged by a lens onto the

PSD, which after signal processing, yields four analog signals indicative of the location of the retroreflector. This approach has been demonstrated to yield accurate position location to better than 0.25 in. (6.35 mm) within a 3-ft (91.44-cm) field of view, at a distance of 30 ft (9.14 m).

This work was done by Ivan Velez of **Kennedy Space Center** and William D. Haskell, Jimmy D. Polk, Robert B. Cox, Jim Strobel, Steve Thayer, and Robert C. Youngquist of I-NET, Inc. Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center; (407) 867-6225. Refer to KSC-11794.

Sight-to-Touch Translator

The tactile principle of Braille printing would be adapted to avoidance of obstacles.

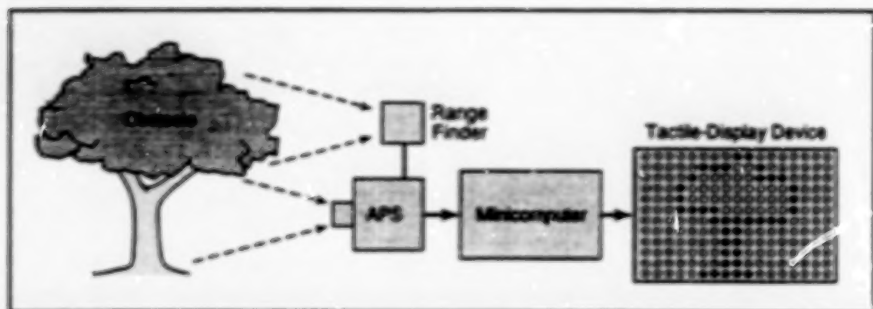
The sight-to-touch translator (ST²) is a conceptual electronic apparatus that would generate a tactile representation of visible objects in its vicinity. The ST² would be worn by a blind person; the tactile display would help the wearer to visualize nearby obstacles and act to avoid them.

Thus, the ST² might serve as an electronic alternative to a guide dog under some circumstances.

The ST² concept has become feasible in recent years, through advances in miniaturized image-detecting electronic devices, processing of image data, and microelec-

NASA's Jet Propulsion Laboratory,
Pasadena, California

tronics in general. The ST² (see figure) would include a state-of-the-art active-pixel sensor (APS) as its image detector. The output of the APS would be digitized and fed to a minicomputer, wherein the image data would be processed through edge-enhancement and gray-scale-based



The Sight-to-Touch Translator would translate the image of a nearby object into a tactile dot representation, which would have characteristics of both Braille and dot-matrix printing.

clutter-detection algorithms. The computer output would comprise data on the outlines of obstacles and other objects in front of the wearer.

The outline data would command the generation of a tactile dot representation of the outline of the object onto a rectangular electromechanical tactile-display device that would look like a giant dot-matrix printing mechanism. The tactile-dis-

play device would have dimensions of about 6 by 10 cm and would be mounted on the wearer's chest, forehead, or other convenient sensitive skin area that would provide a direction reference.

The ST² would include a range finder similar to the range finders on autofocus cameras. Inasmuch as only nearby objects would be of interest for avoiding obstacles, the output of the range finder would be

used to limit the processing of image data to those parts of the scene that lie within a distance of about 5 m.

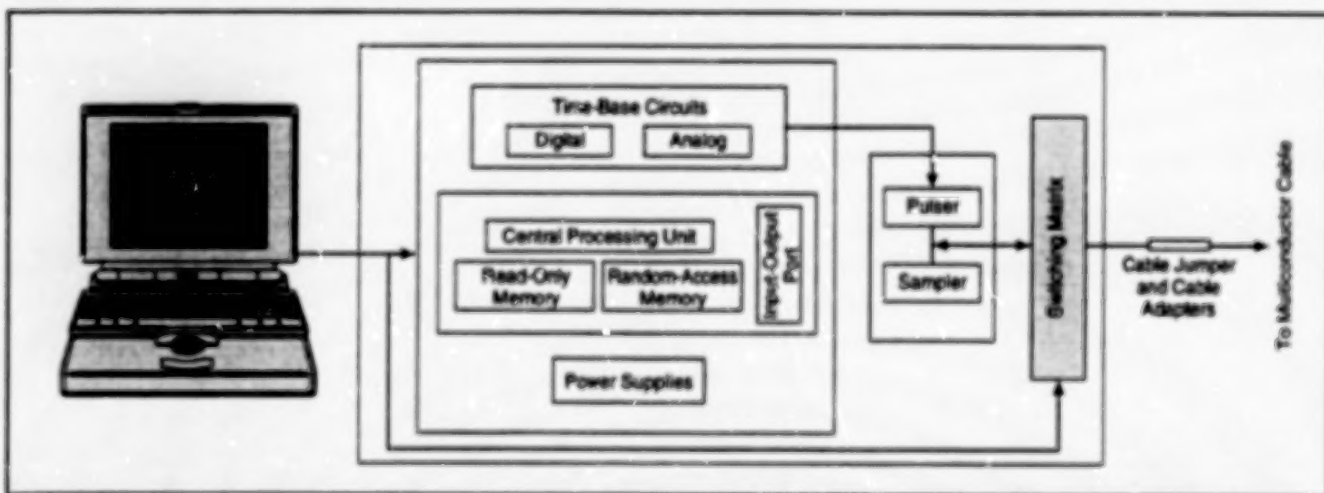
Alternatively or in addition to tactile dot representations of the outlines of obstacles, the apparatus could generate standard tactile dot patterns, analogous to Braille characters, to represent stairs, curbs, doorways, vertical obstacles, and other common objects that the image-processing software would recognize by correlation with previously acquired image data stored in the computer memory. The apparatus could also be made to generate audible signals based on the detection of specified colors in specified configurations (e.g. from traffic lights and illuminated exit signs).

This work was done by Philip I. Moynihan and Maurice L. Langevin of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPC-20230

Automated Cable-Analyzer System — ACAS

A computer-controlled time-domain reflectometer locates faults in multiconductor cables.

Lyndon B. Johnson Space Center,
Houston, Texas



The Automated Cable-Analyzer System includes a time-domain reflectometer and a switching matrix controlled by a laptop computer, which also analyzes the test data. The switching matrix addresses designated pairs of wires in the cable, in a sequence specified via software.

An instrumentation system automates the detection and location of faults in multiconductor electrical cables. It can accelerate diagnoses of aircraft, automotive, or industrial cables, while reducing the incidence of errors and of damage caused by test probes.

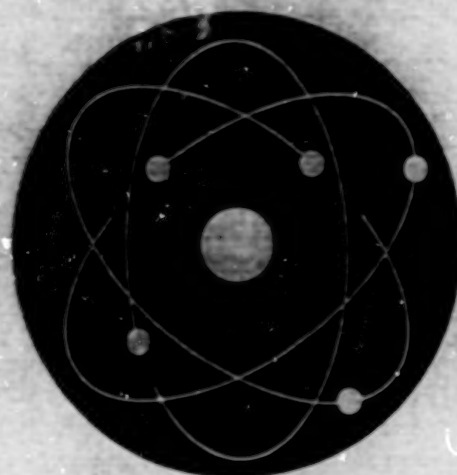
The system (see figure) includes a time-domain reflectometer (TDR), which is a conventional pulse/echo cable-testing instrument. The system also includes a switching matrix containing relay switches, power-supply circuitry, a cable jumper

and an assortment of adapters for mating to a variety of cables, digital control circuitry, and a computer that performs control and data-processing functions. The computer can be programmed to automatically cause the switching matrix to connect the ACAS to different pairs of wires in the cable under test and to analyze and store the measured data.

When connected to the various pairs of wires, the ACAS launches pulses into the cables and samples the reflections. The digitized reflection signals are processed

to locate faults, using a real-time algorithm and/or a more thorough post-processing algorithm. Optionally, post-processing can include comparisons with data acquired previously from cables in known conditions.

This work was done by Michael T. Pham of Johnson Space Center. Further information is contained in a TSP [see page 1].
MSC-22651



Physical Sciences

Hardware, Techniques, and Processes

- 15 Genetic Algorithms Help Design Dielectric Grating Filters
- 16 Radiative Measurement of Temperature in a MESFET Channel
- 17 Convex-Grating Spectrometer With Two Spherical Mirrors
- 18 Equations of State for Fluid Mixtures at High Pressures
- 18 Automated Dew-Point/Frost-Point Humidity Generator
- 19 Improving Distributions of Flux in Solar Thermal Receivers
- 20 Silicon Heat Exchanger for Use at Low Temperatures
- 20 Weighted-Hyperbola Technique for Locating Pulsed Sources

BLANK PAGE

Genetic Algorithms Help Design Dielectric Grating Filters

Genetic algorithms can reveal previously unknown solutions to design problems.

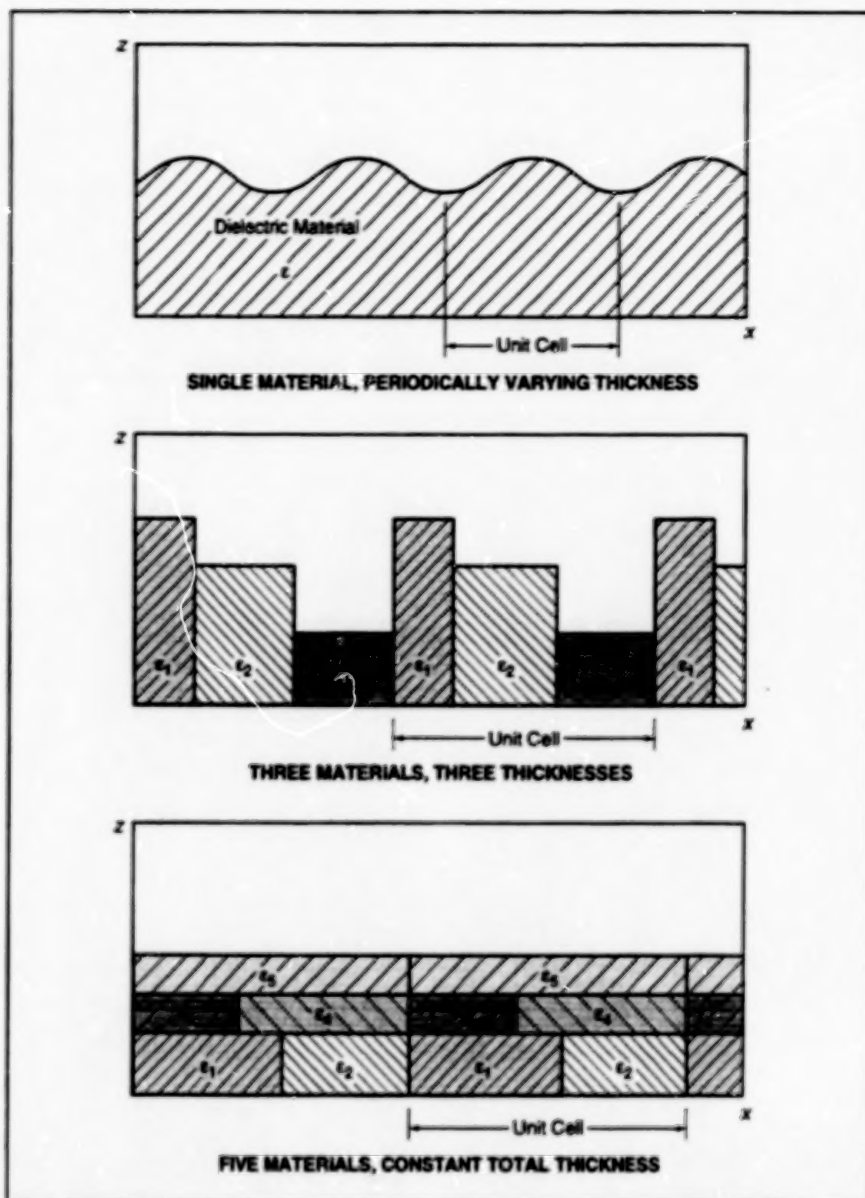
NASA's Jet Propulsion Laboratory,
Pasadena, California

A computational method for designing all-dielectric grating electromagnetic filters involves a combination of (1) numerical simulation of filter performance via integral-equation solution of Maxwell's equations and (2) genetic algorithms to find acceptable combinations of filter-design parameters. The method can be used to design filters of various types (e.g., band-pass, stop-band, or dichroic) for wavelengths from ultraviolet to microwave. One important potential application for the method might lie in the design of all-dielectric microwave dichroic filters for radomes; at present, all-dielectric versions are unknown and the filters are made of metals.

A typical all-dielectric grating filter can be a single- or multiple-layer plate with a periodic inhomogeneity in the dielectric material and/or a periodic variation in thickness (see figure). For the purpose of mathematical modeling, it is assumed that the filter lies in the x - y plane, the periodicity is in the x direction, and the filter is of infinite extent in the y direction and has a thickness t in the z direction. The material in each unit cell or subdivision of a unit cell is characterized by a complex permittivity and possibly by a complex permeability and/or a small conductivity.

The design problem is to find the permittivity, permeability, conductivity, and/or geometric parameters of the periodic structure (hereafter called "material parameters" for short) to obtain an acceptably close approximation to the desired reflectivity or transmissivity as a function of illumination angle and wavelength. This problem shares some of the formalism of the problem of identifying and locating dielectric objects, given the electromagnetic fields scattered from the object; both are nonlinear inverse source problems that involve the same integral-equation solutions of Maxwell's equations: The electromagnetic sources (electric and magnetic current densities) in a given material volume are related to outside electromagnetic fields by a linear integral equation derived from Maxwell's equations. The sources are related to the fields inside the volume by a constitutive equation that includes the material properties. Then the relationship linking the fields outside the source region to those inside is nonlinear in the material properties.

In this method, the nonlinear inverse problem is solved in two linear steps.



Dielectric Grating Filters can have any of a large variety of periodic configurations, of which only a few examples are shown here. In each case, ϵ (with or without a subscript) denotes the complex permittivity of the material.

For this purpose, the electromagnetic sources in the computational material volume are introduced as unknowns in addition to the material unknowns, making it possible to solve for source-volume fields and material parameters consistent with Maxwell's equations. Solutions are obtained iteratively by decoupling the two steps. First, one inverts for the material parameters only as part of a process of minimization of a cost function that is a measure of the deviation between the synthesized and desired reflectivity or transmissivity

response. Next, given the material parameters, one computes the electromagnetic fields through direct solution of the integral equation in the source volume. The sources thus computed are used to compute the far fields and thus the synthesized transmissivity or reflectivity response of the filter.

The inversion to compute the material parameters is performed by use of a genetic-algorithm software package, called "PGAPACK," that incorporates capabilities for parallel processing. Genetic algorithms offer advantages

over gradient-based and other local search methods for this and other electromagnetic-design problems, the solution spaces of which contain many extrema of cost functions. The ability of genetic algorithms to search parameter spaces globally not only makes it possible to avoid the common pitfall of converging on local (but not global) minima, but also holds promise for finding previously unknown solutions. The possibility of finding previously unknown solutions is especially important in that it could enable one to design relatively simple or

otherwise preferable filters and to investigate trends in material parameters.

The most expensive part of the computational cycle is solving for the electromagnetic fields. The computational burden is reduced by use of a matrix-vector formulation in which a set of frequency-dependent matrices need be filled only once. In addition, the number of frequencies for which the design equations are solved is reduced by using a transfer-function parameter-estimation technique in which the desired filter response is expressed as a quotient of frequency-

dependent polynomials. The computation time is reduced further by taking full advantage of parallel-processing capabilities of PGAPACK on a Cray T3D computer. The parallelization scheme involves a simple master/slave configuration, with the expensive evaluation cycle distributed among the processors.

This work was done by Cinzia Zuffada and Tom Cwik of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1]. NPO-20158

Radiative Measurement of Temperature in a MESFET Channel

Temperature can be determined with a spatial resolution of about 0.5 μm .

NASA's Jet Propulsion Laboratory,
Pasadena, California

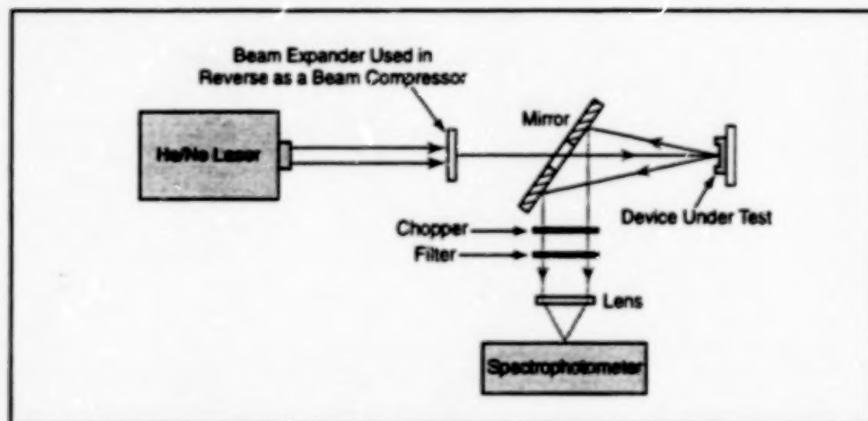


Figure 1. A Laser Beam impinges on a small spot on the device under test. Spectral measurement of the resulting infrared emission can be used to determine the temperature in the illuminated spot.

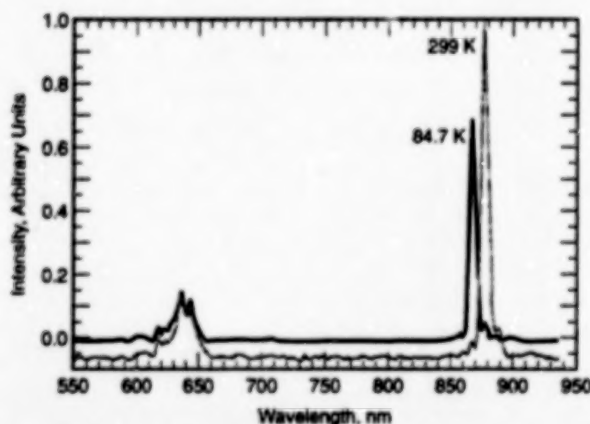


Figure 2. These Infrared Emission Spectra were acquired at different device temperatures. Note that the wavelength shift between the spectral peaks for the two temperatures.

A technique based on infrared-emission spectroscopy has been found to be useful for noncontact measurement of the temperature of a hot spot in the gate channel of a GaAs metal/semiconductor field-effect

transistor (MESFET). Temperature measurements are important for the development of high-power GaAs MESFET and other advanced semiconductor devices because hot spots can affect operation

and reduce operational lifetimes. An older passive infrared-sensing technique provides temperature measurements with a spatial resolution of 15 μm , which is much too coarse for determining local distributions of temperature in state-of-the-art devices with submicron-sized gate structures. The present technique affords a spatial resolution of about 0.5 μm .

The technique involves the use of parts of an apparatus called the "microelectronic advanced laser scanner" (MEALS), which was described in a number of articles in *NASA Tech Briefs* during the years 1992 and 1993. As shown in Figure 1, the beam from a helium/neon laser is aimed at the device under test. A micromanipulator stage with a resolution of 0.1 μm is used to position the device under test so that the laser beam impinges at the gate position of the device. Light emitted from the illuminated spot on the device is collected by a mirror, chopped, and focused onto a spectrophotometer. The light is also low-pass filtered to discriminate against the light at the illuminating laser wavelength. The photodetector in the spectrophotometer is a cooled photomultiplier tube, and its output is processed through a lock-in amplifier synchronized with the chopper. The output of the lock-in amplifier is digitized, then processed in a personal computer to obtain the spectrum of infrared emission stimulated by the laser beam.

The technique exploits the temperature dependence of the wavelength of the peak of the stimulated-infrared-emission spectrum. In general, this wavelength increases approximately linearly with temperature—a consequence of the fact that the energy-band gap of a semiconductor material decreases with temperature.

Thus, if the temperature dependence of this wavelength is known, it can be used to determine the local temperature in the device operating at various power levels.

The technique was demonstrated on a GaAs MESFET, with no power applied to it, at temperatures of 84.7 and 299 K. As shown in Figure 2, the peak wavelength for the higher temperature exceeded that

for the lower temperature by about 10 nm. In another measurement run not indicated in the figure, the exterior of the device was maintained at 84.7 K and power was applied; the peak wavelength for this case was 4.5 nm greater than that for the zero-power case at 84.7 K. By linear interpolation, this wavelength shift indicates that under power, the temperature of the gate

rose about 96 K above the exterior temperature of 84.7 K.

This work was done by Quiesup Kim and Sammy A. Kayali of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20120

Convex-Grating Spectrometer With Two Spherical Mirrors

Compact, well-corrected optics would be suitable for imaging spectroscopy in commercial applications.

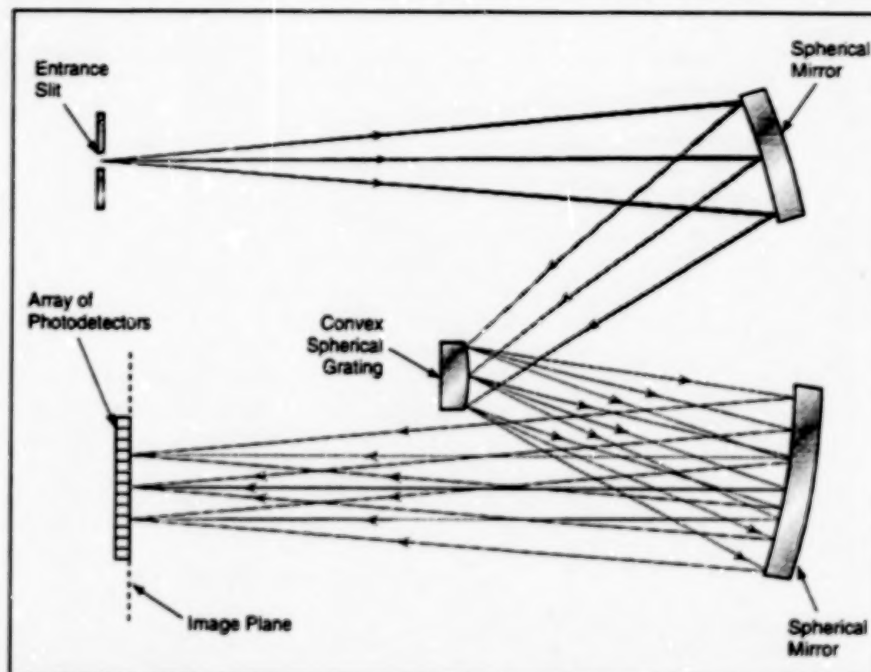
NASA's Jet Propulsion Laboratory,
Pasadena, California

The figure shows the basic optical configuration of an improved all-reflecting imaging spectrometer. This spectrometer would differ from older spectrometers in several respects, one being its convex spherical diffraction grating: heretofore, spectrometers have contained, variously, concave or plane diffraction gratings. The specific design, featuring the convex grating and two concave spherical mirrors, would afford a wide field of view and a compact layout that would make the size of this spectrometer about 1/3 that of a spectrometer of typical older design and similar capabilities. The sphericity of the optical surfaces would make fabrication relatively easy and inexpensive.

The radii of curvature of the grating and mirrors and the off-axis positions and angles at which these optical components would be mounted have been selected to give the excellent spatial and spectral performance over the image plane. The spectrometer would produce a well-corrected, spectrally dispersed image of the entrance slit over a wide spectral range. The outstanding quality of the image would be attributable to good correction of astigmatism and field curvature over the image area. Heretofore, it has been extremely difficult to achieve correction of both field curvature and astigmatism over the image areas of imaging spectrometers.

The all-reflecting design would be suited for spectral regions from vacuum ultraviolet through visible to far infrared. Unlike in older imaging spectrometers, there would be no need for a field-flattening lens: this would constitute a major advantage for operation over extended spectral regions. The relative flatness of the focal plane would make this spectrometer suitable for use with a planar array of photodetectors.

The design would use the variation of astigmatism of the second mirror with wavelength to compensate for the variation



The Ray-Trace Diagram illustrates the basic function of the convex-grating spectrometer. In this view, the long dimension of the entrance slit and thus the spatial axis of the image plane lie perpendicular to the page, while the spectral dispersion axis of the image plane lies on the dotted line in the page.

of astigmatism of the grating with wavelength. The design would use the variation of astigmatism of both mirrors with field angle to compensate for the variation of astigmatism of the grating with field angle. The design would also use both spherical mirrors to compensate for the spectral and spatial field curvature intrinsic to the grating. Though the design does not look complicated, the process of optimizing the design was complicated because it involved careful selection of design parameters to balance astigmatism, field curvature, and coma over the spatial and spectral fields.

Design calculations show that in both the spectral and spatial aspects, the optical performance of this spectrometer would exceed that of any imaging

spectrometer now in existence. Excellent spatial resolution perpendicular to the spectral dispersion axis would make this instrument attractive for a variety of industrial and medical applications that have already given rise to a multimillion-dollar market in imaging spectrometers.

This work was done by Michael P. Chrisp of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 1]. Refer to NPO-19293.

Equations of State for Fluid Mixtures at High Pressures

This method is particularly applicable to gas turbine and rocket engines.

NASA's Jet Propulsion Laboratory,
Pasadena, California

Substance	Temperature Range, K	Pressure Range, MPa	Maximum rms Relative Error (Percent at Fixed Pressure)		
			Enthalpy	Entropy	pv/RT
Hydrogen	80 to 400	0.1 to 100	0.23	0.15	1.0
Oxygen	100 to 400	0.1 to 100	1.1	0.2	1.4
Nitrogen	100 to 2000	0.1 to 100	0.22	0.22	0.7
Propane	100 to 600	0.1 to 100	2.9	0.5	2.0
Methane	100 to 600	1 to 30	0.9	0.3	1.0
N-heptane	210 to 1500	0.1 to 27	0.26	0.16	2.2
Methanol	210 to 1500	1 to 80	1.35	1.1	10

Reference-State Fits were made for seven substances in various pressure and temperature ranges. The fit for each substance is characterized by a maximum root-mean-square (rms) relative error at fixed pressure.

A method that includes the use of modified equations of state has been developed to enable noniterative, efficient computation of the thermodynamic behaviors of gases and liquids at temperatures ≥ 100 K and pressures from 1 to 100 MPa. The method is intended to be particularly useful for calculating such quantities as partial molar volumes, enthalpies, entropies, compressibilities, and thermal expansivities of oxidant/fuel mixtures at given pressures, temperatures, and mass fractions in gas turbine and rocket engines.

The method is based partly on the concept of a reference state of a real gas, which state is similar to that of a

perfect gas at the same temperature and pressure and is defined with respect to the condition of the real gas at a relatively low reference pressure. The method is also based partly on the use of departure functions to represent the deviations of thermodynamic functions of the real gas at high pressure from reference-state values of those functions.

The form of the departure functions is obtained from the Peng-Robinson equation of state:

$$p = RT/(v - b_m) - a_m/(v^2 + 2b_mv - b_m^2),$$

where p is the absolute pressure, R is the molar ideal-gas constant, T is the

absolute temperature, and v is the molar volume. The parameters a_m and b_m are semiempirical terms calculated from critical-state properties; these parameters follow conventional mixing rules; namely,

$$a_m = \sum \sum x_i x_j a_{ij} \text{ and } b_m = \sum x_i b_i,$$

where x_i is the mole fraction of the i th molecular species.

One first applies the departure-function formalism to each of the pure constituents of a mixture, then reuses this formalism for the mixture as a whole. In the application to each pure constituent, one expresses the reference-state enthalpy and entropy as finite series of temperature- and pressure-dependent terms, the coefficients of which are established by least-squares fits to the best available empirical data on enthalpy and entropy (see table). This method follows the standard practice in calculating the properties of nonideal mixtures by use of accurately known properties of the pure constituents along with excess Gibbs energy and/or fugacity coefficients, which are defined by use of conventional mixing rules.

This work was done by Josette Bellan, Richard S. Miller, and Kenneth G. Harstad of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].

NPO-20066

Automated Dew-Point/Frost-Point Humidity Generator

Thermal mass-flow controllers are used to provide repeatable and stable humidity.

NASA's Jet Propulsion Laboratory,
Pasadena, California

The figure schematically illustrates an improved apparatus for generating a flow of gas with precise, stable humidity. Such flows are needed for calibration of dew-point, frost-point, and other humidity sensors.

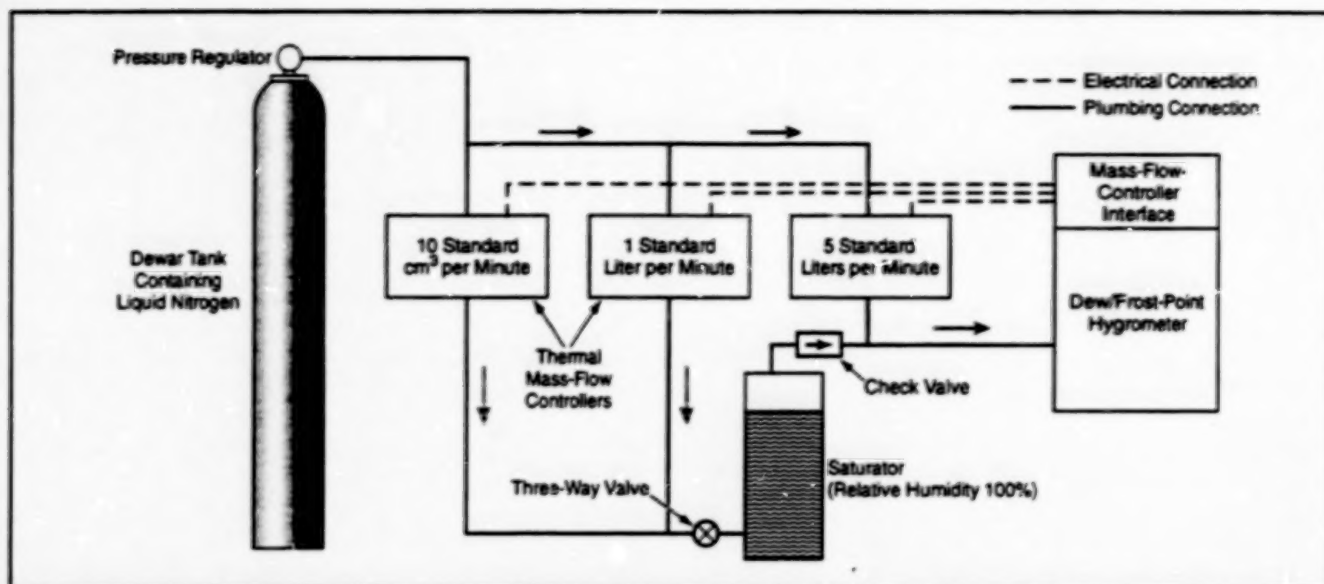
Like a prior humidity generator, this apparatus utilizes a divided-flow technique, in which an initially dry gas to be humidified is divided into two streams, one stream is humidified in a saturator, then the two streams are recombined to obtain a single stream with the required humidity. The flows in the prior humidity

generator were regulated by use of differential-pressure flow controllers, which required manual adjustment, were highly unstable, and gave nonrepeatable flow rates. In addition, the proper operation of the prior humidity generator depended on constant attention by a technician to perform hygrometer calibrations.

The instability and imprecision of the prior humidity generator are eliminated in the improved apparatus by replacing the differential-pressure flow controllers with thermal mass-flow controllers that, in turn, can be controlled by a computer. In addition,

the mass-flow controllers are placed upstream of the saturator, preventing contamination and increasing stability. These two innovations provide much greater precision in the flow rates used to produce desired levels of humidity. The improvements also reduce the labor time needed to perform a hygrometer calibration from 8 hours to about 2 hours.

This work was done by Miguel Cerezo of Caltech for NASA's Jet Propulsion Laboratory. No further documentation is available.
NPO-19935



Thermal Mass-Flow Controllers are used instead of differential-pressure mass-flow controllers, and are placed upstream of the saturator.

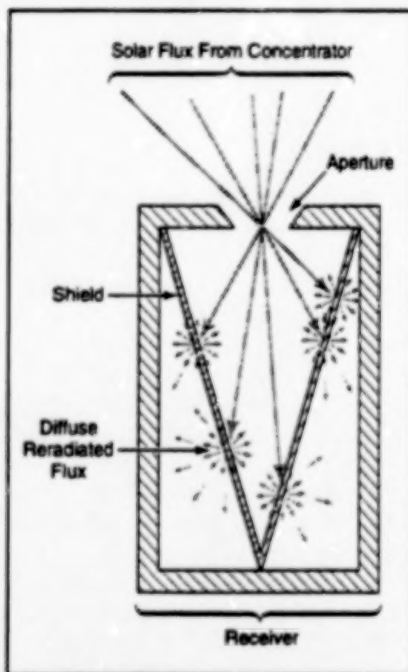
Improving Distributions of Flux in Solar Thermal Receivers

Concentrated radiant flux would be absorbed and reradiated by shields.

*Lyndon B. Johnson Space Center,
Houston, Texas*

A modification of design has been proposed to extend the longevity of cavity-type solar thermal receivers by improving the distribution of radiant solar flux in the cavities. A receiver of this type is used in conjunction with a solar concentrator, which is a mirror that focuses the radiant solar flux into the cavity. A large part of the radiant flux is absorbed on the inner cavity walls and is thereby converted to usable heat. Inevitably, imperfections in the surface of the concentrator give rise to a maldistribution of flux in the cavity — hot spots — that shorten the useful life of the receiver.

The proposed modification consists mainly of the addition of a thermally conductive, thermally emissive radiant shield between the aperture and the walls of the cavity (see figure) to even out the hot spots. Concentrated solar flux would enter the cavity through the aperture in the usual way, but would be initially absorbed on the shield and would thus initially heat the shield instead of the inner cavity walls. The heat would be conducted through the shield from the side facing the aperture to the side facing the inner cavity walls.



The Shield Would Absorb concentrated solar radiant flux and reradiate heat diffusely to the cavity walls, thus evening out hot spots in the concentrated flux.

Being hot on both sides [typical temperature of 1,550 °F (843 °C)], the shield would reradiate diffusely toward the

inner cavity walls, toward the aperture, and toward facing parts of the shield itself. The diffuseness of the reradiation would diffuse the hot spots, so that the temperature [typical temperature 1,400 °F (760 °C)] around the circumference of the inner wall would be more nearly even.

The fraction of reradiated heat lost through the aperture would be greater than it is in a comparable receiver of unmodified design (without a shield). However, the loss could be reduced to a few percent or perhaps eliminated by suitable choice of the size and shape of the shield, the rest of the receiver, and the concentrator. In any event, the economic disadvantage of the small loss of energy-conversion efficiency may be more than offset by economic advantages of (1) the increase in useful life and (2) the decrease in cost of the concentrator occasioned by elimination of the need to carefully tailor the concentrated flux to minimize hot spots.

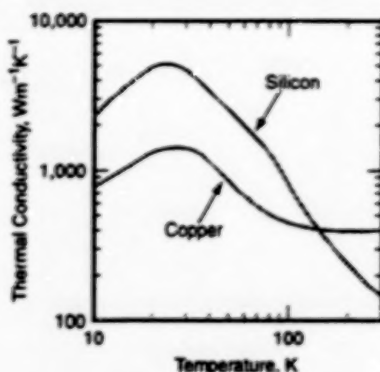
This work was done by Charles T. Kudja of Rockwell International Corp. for **Johnson Space Center**. Further information is contained in a TSP [see page 1]. MSC-22553

Silicon Heat Exchanger for Use at Low Temperatures

Narrow flow passages are fabricated to high precision by micromachining.

A heat exchanger made largely from pieces of single-crystal silicon has been designed for use as a recuperator in a reverse-Brayton-cycle cryocooler. Its design is optimized for transferring heat between counterflows of neon at a mass flow rate of 0.7 g/s, with an inlet temperature of 300 K and pressure of 2.21 atm (0.224 MPa) on the warm side and an inlet temperature of 60 K and pressure of 1.3 atm (0.13 MPa) on the cold side.

Ordinarily, one might be inclined to make a heat exchanger from a highly thermally conductive metallike copper. However, single-crystal silicon offers advantages over copper in this particular application. One advantage pertains to thermal conductivity. The thermal conductivity of single-crystal silicon ranges from less than that of copper at room temperature to greater than that of copper at cryogenic temperatures. Detailed heat-transfer calculations performed with known conductivity-vs.-temperature data (see figure) have shown that on balance, the superior low-temperature thermal conductivity of



The Thermal Conductivity of Silicon exceeds that of copper in the lower part of the intended range of operating temperatures.

silicon prevails in the specific intended application. This makes it possible to obtain better heat-transfer performance in a heat exchanger of given size, shape, and complexity; or, alternatively, to obtain equivalent heat-transfer performance in a smaller and/or less complex heat exchanger.

NASA's Jet Propulsion Laboratory,
Pasadena, California

Another advantage of silicon is that established technology for micromachining of single-crystal silicon by photolithography, etching, and related techniques is commercially available. Thus, silicon components with multiple narrow and/or short flow passages can readily be fabricated to obtain flow and thermal-conduction geometries that are defined with high precision to optimize heat-transfer performance.

Yet another advantage of silicon is that its mass density is only 2.33 g/cm³, whereas that of copper is 8.92 g/cm³. As a result, a silicon heat exchanger weighs about 74 percent less than does an identically sized and shaped copper heat exchanger for the intended operating temperatures.

This work was done by Thomas J. Jasinski and William E. Nutt of Creare, Inc., for NASA's Jet Propulsion Laboratory. No further documentation is available.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 1]. Refer to NPO-30021.

Weighted-Hyperbola Technique for Locating Pulsed Sources

The weighted-hyperbola technique is an iterative computational technique for processing data on the times of arrival of pulsed signals at more than four observing stations to determine location (in both space and time) of origin of the signals. (The location is overdetermined when data from more than four stations are available). The technique was developed especially for use in processing data on electric-field signals to locate lightning sources and is expected to be particularly beneficial in cases in which the sources are near the ground. On

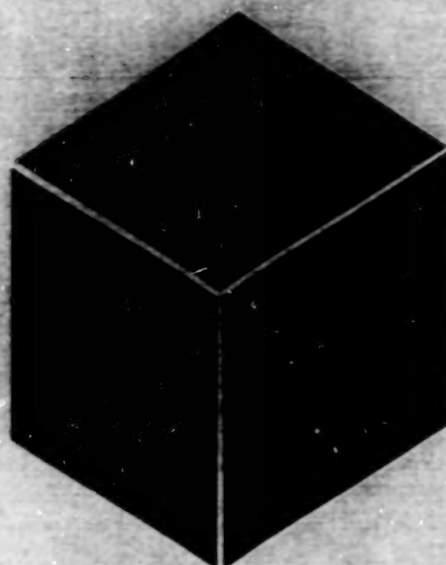
each iteration, a "best estimate" of the location of the source is computed as a weighted average of locations from all possible four-station combinations of readings. The weight for each spatial coordinate for each four-station combination is proportional to the reciprocal of the variance for that coordinate and four-station combination, where the variance is based on the previous best estimate.

This work was done by Ewen M. Thomson of the University of Florida for Kennedy Space Center. Further information is contained in a TSP [see page 1].

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Ewen M. Thomson
University of Florida
Dept. of Electrical Engineering
P.O. Box 116200
Gainesville, FL 32611

Refer to KSC-11861, volume and number of this NASA Tech Briefs issue, and the page number.



Materials

Hardware, Techniques, and Processes

- 23 Alumina/Ethanol Colloidal Suspensions for Seeding Hot Flows
- 23 Two Methods for Purifying Carbon Tetrachloride
- 24 Coating SiC Fiber Tows With Polymer/Silicon Slurries
- 24 Nitrogen-Beam Source for Deposition of III/V Nitrides

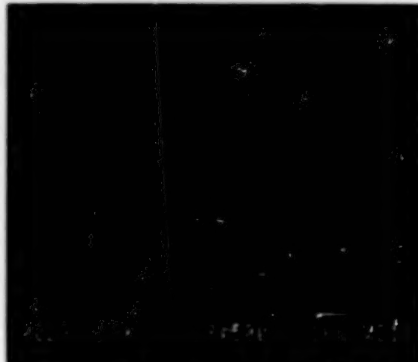
Alumina/Ethanol Colloidal Suspensions for Seeding Hot Flows

These suspensions are stabilized by adjustment of pH.

Lewis Research Center, Cleveland, Ohio

The alumina for making a suspension according to this concept must be in the form of a highly pure (preferably >99.99 percent) powder with a suitable particle-size distribution — preferably monodisperse with a mean particle size of a fraction of a micron, as illustrated in the figure. The alumina powder is mixed with an ethanol solution, the pH of which has been lowered to a predetermined value (typically between 1 and 5) as explained below. The amounts of alumina powder and ethanol solution are chosen to obtain the desired concentration of solid material in the suspension. Optionally, the suspension can be made initially in a high concentration (e.g., 20 weight percent alumina), then diluted. During mixing or dilution, the liquid and solid contents are agitated with an ultrasound to break up agglomerations of particles.

The lowering of the pH of the ethanol solution to a predetermined value is effected by addition of a suitable amount of 1N HCl. The predetermination is based on the following principle: In a polar aqueous solution or a polar noneaqueous liquid



This Scanning Electron Micrograph shows particles of alumina powder with a mean particle size of $0.7 \pm 0.2 \mu\text{m}$. Most of the particles are roughly spherical and small enough to be suitable for use in seeding flows.

like ethanol, the surfaces of the particles become electrically charged by amounts that depend on the pH, among other factors. The stability of the suspension depends on the sign and magnitude of the total energy of interaction among the particles. One can choose a value of pH for which the amount of surface charge is large enough that the resulting electrosta-

tic repulsion among particles is sufficient to overcome the attractive London-van der Waals forces that cause agglomeration. Thus, the chosen pH should be far from that value of pH (called " pH_{zpc} " for which the surface charge is zero). In general, different grades of alumina powder and alumina powders from different manufacturers exhibit different values of pH_{zpc} . The pH_{zpc} of the powder to be used in a specific application must be determined precisely by titration or approximately via sedimentation tests.

This work was done by Mark P. Wernet of Lewis Research Center, Gary J. Skoch of the Vehicle Technology Center of the U. S. Army Research Laboratory, and Judith H. Wernet of Case Western Reserve University. Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16423.

Two Methods for Purifying Carbon Tetrachloride

Purity exceeds that achievable by simple distillation.

Marshall Space Flight Center, Alabama

Two methods have been developed to purify large batches of technical-grade carbon tetrachloride. The relatively impure carbon tetrachloride that had been purchased for use in infrared analysis of dissolved hydrocarbons proved that it could be purified. One method is spinning-band distillation, which is a special type of fractional distillation. The other method involves the use of a molecular sieve, which is a material that is formulated to have special porosity and adsorbent properties and can physically "suck" substances (e.g., the impurities that one seeks to remove from CCl_4) into its pores.

To be useful as a solvent for infrared analysis, CCl_4 must be very pure. The two methods were investigated as alternatives to simple distillation, which was known to be insufficient for achieving the required purity for two reasons: (1) in general, simple distillation does not remove impurities (e.g., other solvents) that have boiling temperatures near that of the solvent that one seeks to purify and (2) the technical-grade CCl_4 that was to be purified had been pro-

duced by simple distillation.

Spinning-band distillation involves the use of a thin band rotating rapidly in a narrow-bore distillation column. The condensate returning to the pot is wiped by the band in a very thin layer along the bore. The returning condensate makes contact with the counterflowing, rising vapors. The net result, in comparison with that achievable by simple distillation, is better separation of constituents with higher boiling temperatures from constituents with lower boiling temperatures. The improvement in separation is attributable to enrichment of the vapor in the more volatile constituents.

Although the spinning-band distillation method was effective, it was decided that an attempt should be made to develop a faster and perhaps even more effective method. Gas chromatography coupled with mass spectrometry (GC-MS) and infrared spectrometry had indicated that most, if not all, of the impurities were polar molecules. So it was decided to try to develop a method that would preferential-

ly remove polar molecules from this non-polar solvent (CCl_4). It was reasoned that molecular sieves might be able to achieve such preferential adsorption. Several were tried and one was found that adsorbed the impurities as desired.

In this method, an activated molecular sieve is immersed in the solvent in a glass container. Optionally, one can stir the solvent to bring more of the solvent into contact with the molecular sieve within a given time and thereby accelerate the purification process. By experimentation with several different molecular sieves, the Linde 13X (or equivalent) molecular sieve was found to be exceptionally effective in removing impurities from CCl_4 . The Linde 13X molecular sieve has a pore size of $10 \text{ \AA}$.

In comparison with spinning-band distillation, purification by use of this molecular sieve was found to be faster. In addition, the concentration of impurities (1 part per million) remaining after contact with the molecular sieve was found to be less than that remaining after spinning-band distillation. Yet another advantage

of the molecular sieve is that it can be regenerated and reused. Recent advances in the synthesis of molecular sieves suggest that it may be possible to tailor the pores and/or constituents of a

molecular sieve to remove selected impurities from a liquid.

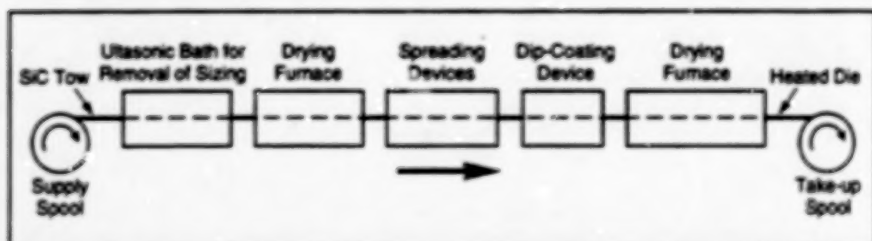
This work was done by Raymond P. Skowronski and Carl J. Schack of the Rocketdyne Division of Boeing North

American for Marshall Space Flight Center. Further information is contained in a TSP [see page 1].
MFS-30132

Coating SiC Fiber Tows With Polymer/Silicon Slurries

The coated fibers are used to make $\text{Si}_3\text{N}_4/\text{SiC}$ composites.

Lewis Research Center,
Cleveland, Ohio



A Tow of SiC Filaments is Drawn through an apparatus that coats it with a silicon/polymer slurry.

The figure schematically illustrates an apparatus and process in which a continuous tow of silicon carbide fibers is coated and infiltrated with a polymer/silicon slurry. A compact of such coated, infiltrated fiber tows is subsequently heated to a temperature $\geq 1,200^\circ\text{C}$ in nitrogen to convert it to one of a variety of materials, denoted generally as "SiC/RBSN," that are composites of silicon carbide fibers in reaction-bonded silicon nitride matrices. SiC/RBSN composites are candidates for use in structural components for some high-temperature applications.

A slurry of the type used in this process consists of silicon particles with a mean diameter of $0.3\text{ }\mu\text{m}$ suspended in an isopropyl solution of a polymeric binder. The use of submicron silicon particles and the choice of proportions of the other ingredients to achieve low viscosity of the slur-

ry are necessary to ensure infiltration of the slurry into the interstices of the tow. A fiber tow of the type used in this process typically consists of nearly 500 filaments of ceramic-grade SiC, each with a diameter of about $15\text{ }\mu\text{m}$. The fibers as manufactured are coated with a sizing of polyvinylacetate, which must be removed in the process to make room for infiltration by the silicon particles.

The tow is drawn from a supply spool, through the apparatus and process, to a take-up spool. After coming off the supply spool, the tow first passes through a few cylinders that contain solutions of equal volume proportions of isopropyl alcohol and water. The solutions are heated to a temperature between 35 and 55°C and agitated ultrasonically. The sizing would ordinarily be insoluble in static isopropyl alcohol/water solutions,

but with the ultrasonic agitation, the solutions gradually dissolve the sizing.

After emerging wet from the last sizing-removal bath, the tow is drawn through a drying furnace. The dried tow passes into a spreading device, wherein air is blown across the tow, creating vibrations and spreading the fibers out. In addition, an electrostatic generator puts electrostatic charges on the passing fibers, so that mutual electrostatic repulsion will enhance spreading.

The spread tow is plunged into a dip-coating device, where it is coated and infiltrated with the slurry. The coated, infiltrated tow then passes through a second drying furnace. As the tow emerges from the furnace, it is consolidated by drawing it through a heated circular die. Typical drying and die temperatures range from 110 to 190°C .

This work was done by Rickmond C. Chan at Lewis Research Center. Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16516.

Nitrogen-Beam Source for Deposition of III/V Nitrides

This apparatus improves the synthesis of wide-band-gap nitrides.

Marshall Space Flight Center

A nitrogen-beam source has been developed to significantly improve the synthesis of wide-band-gap nitrides.

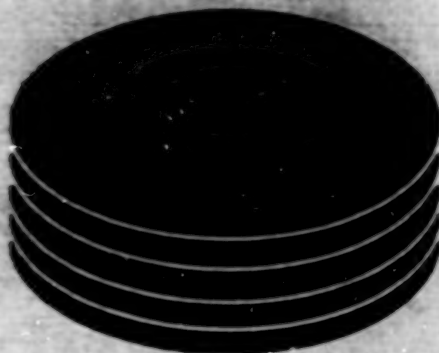
In experiments supported by the Department of Defense and NASA, thin nitride films have been grown by use of a unique neutralizer for atomic-beam source (NABS). The NABS is a simple device—a hollow metal cone. When the NABS is attached to a broad-beam ion source that emits nitrogen ions, these ions become neutralized, focused, and dissociated through collisions on the inside conical surface.

Although it is extremely simple to construct, this device made it possible to grow some of the first thin films of cubic boron nitride. The NABS was subsequently used in creating buffer gallium nitride layer structures on which high-mobility thin films of gallium nitride were grown by use of an electron cyclotron resonance source.

The potential use of an ion source with a high flux of atomic neutral species from an end-Hall system could be very important to the growth of compounds of (1) nitrogen and other elements from period V and (2)

elements from period III of the periodic table. The promising initial growths in the boron nitride system indicate that these materials may be better suited to ion-beam deposition methods and less sensitive to damage than when grown by conventional (non-ion-beam) deposition methods.

This work was done by J. Albert Schultz, of Ionwerks, for Marshall Space Flight Center. Further information is contained in a TSP [see page 1].
MFS-26464



Computer Programs

Materials

- 27 Program for Microanalysis of Composite Structures

Machinery

- 27 Software for Tooth-to-Tooth Contact Analysis of Spiral Bevel Gears

Mathematics and Information Sciences

- 27 Software for Retrieval and Display of Planetary Data
28 Program for Design Analysis of Cache Memory

Computer Programs

These programs may be obtained from COSMIC. Please contact

COSMIC*

Computer Services Annex
University of Georgia
Athens, GA 30602
Telephone No. (404) 542-3265.

Materials

Program for Microanalysis of Composite Structures

Phenomena that can be analyzed include elastostatics, heat transfer, thermoelasticity, elastoplasticity, and creep.

Version 3.0 of the Boundary Element Solutions Technology Composite Modeling System (BESTCMS 3.0) is an advanced engineering software system for the micro-analysis of fiber composite structures. BESTCMS is based on the BEST3D boundary-element program (COSMIC program LEW-15351). BESTCMS affords capabilities for analyses of elastostatic behavior, steady-state and transient heat transfer, steady-state and transient concurrent thermoelasticity, elastoplasticity, and creep.

In BESTCMS, the fibers can be assumed to be perfectly bonded to the matrix in a composite material; alternatively, in static or steady-state analysis, one can assume that there are spring connections, thermal resistance and/or frictional sliding between the fibers and the matrix.

BESTCMS is written in FORTRAN 77 to be machine-independent across UNIX platforms. BESTCMS has been successfully implemented on the following computers and operating systems: SUN 4 IPC running Solaris 2.1 (SunOS 5.4), SGI IRIS Indigo2 running IRIX 6.2, HP 9000/720 running HP-UX A.09.01, and IBM RS/6000 running AIX 4. For efficient execution, BESTCMS requires a minimum of 8MB of random-access memory; for efficient execution in cases of practical three-dimensional problems, 300MB of temporary disk storage capacity is recommended. The standard distribution medium for BESTCMS is one 4-mm DAT cartridge in UNIX tar format. Alternate distribution media are

available upon request. BESTCMS 3.0 was released to COSMIC in 1997.

This work was done by D. A. Hopkins of Lewis Research Center and P. K. Barerjee and D. P. Henry of the State University of New York at Buffalo. Further information is contained in a TSP [see page 1].
LEW-16472

Machinery

Software for Tooth-Contact Analysis of Spiral Bevel Gears

Sources of transmission errors are analyzed in order to minimize vibrations.

The SBTAPER computer program implements a method for design and generation of spiral bevel gears that feature tapered teeth with localized bearing contact and a low level of transmission errors. The influence of misalignment on transmission errors and shift of bearing contact were investigated in the development of the method.

The SBTAPER approach emphasizes detection and avoidance (i) of vibration caused by misalignment and (ii) of an edge contact caused by interference between the working part of the surface of a gear with the fillet surface of the mating gear. The main features of this approach are the following:

1. The localization of the bearing contact is achieved by the mismatch of the generating surfaces. The bearing contact can be provided in the longitudinal direction or in the direction across the surface.
2. The low level of transmission errors is achieved because of application of non-linear relations between the motions of gears and of gear-head cutters. Such relations can be obtained from application programs for computer numerically controlled (CNC) machine tools. The generation of a pinion is based on linear relations between the motions of the pinion and of the tool used to make the pinion. These relations make it possible to obtain a parabolic function of transmission errors that can absorb almost-linear functions caused by misalignment. SBTAPER is written in FORTRAN 77

for IBM-PC-compatible computers. The IMSL libraries and a FORTRAN compiler are required. No executable code is provided because input data are entered directly into the source code. SBTAPER has been successfully executed on a 486 computer running Windows 95 with Microsoft Fortran Powerstation 4.0. The standard distribution medium for SBTAPER is one 3.5-in. (8.89-cm) diskette in MS-DOS format. The contents of the diskette have been compressed by use of the PKWARE archiving software tools. SBTAPER was released to COSMIC in 1997.

This program was written by F. L. Utvin and A. Wang of the University of Illinois at Chicago and R. F. Handschuh of the Army Research Laboratory for Lewis Research Center. Further information is contained in a TSP [see page 1].
LEW-16493

Mathematics and Information Sciences

Software for Retrieval and Display of Planetary Data

The NASAView computer program provides access to, and display of, sets of scientific data in the Planetary Data System (PDS) archive. These data — totalling about 5 terabytes — were acquired during NASA's planetary-exploration missions and are stored along with descriptive information useful for retrieving and interpreting the data. NASAView is designed to be usable on multiple platforms (including Sun/Unix, Apple Power PC, and PC/Win32 computers and operating systems). NASAView converts between machine-specific data representations as necessary and provides graphical user interfaces (GUIs) with a common look and feel on all the platforms. NASAView incorporates the PDS Label Library Light (L³) and the PDS Object Access Library (OAL), which are the standard software libraries for production and use of the PDS archive. The L³ reads and parses a data-product label and provides access to label information by use of standard function calls. Using the label information, the OAL manipulates the sci-

entific data at the physical-record, data-representation, and object (data-product-as-a-whole) layers. NASAView also incorporates the XVT Portability Toolkit™ software, which provides the capabilities for development and use of common GUIs on different platforms and ensures the same application functionality on the various platforms.

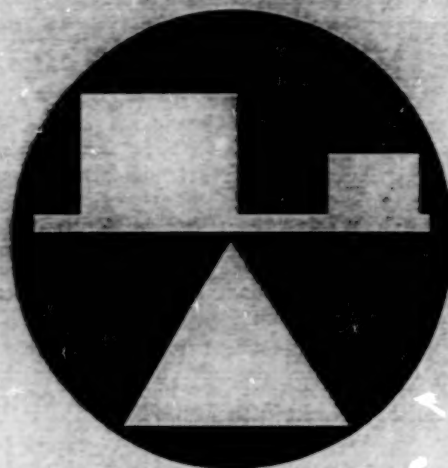
This program was written by John S. Hughes and Michael D. Martin of Caltech, Luke T. Fu of MIT, and Todd King of UCLA for NASA's Jet Propulsion Laboratory. For further information, please contact the PDS Operator at PDS.Operator@jplpds.jpl.nasa.gov. NPO-19795

Program for Design Analysis of Cache Memory

CACHESIM is a C-language computer program that simulates (1) cache-memory options associated with a computer hardware design concept and (2) related properties that can be expected to affect the overall performance of the computer, before the computer is constructed. Herein, the performance effects of cache-memory options were investigated through hardware monitoring. **CACHESIM** provides for selection of options that include hardware organization, cache size, line size, replacement policy, write-hit policy, write-miss policy, fetch policy, simulated

processor speed, processor instruction-execution clock cycles, and cache-miss clock-cycle penalty. For a given combination of options, the output of **CACHESIM** includes appropriate hit and miss rates, central-processing-unit time, and the number of memory stall cycles incurred. This information is useful in determining the overall effectiveness and performance of the cache design.

This work was done by José J. Amador of Kennedy Space Center. Further information is contained in a TSP [see page 1]. KSC-11924



Mechanics

Hardware, Techniques, and Processes

31 Gas Buffer Seal

Books and Reports

31 Flexible Actuators for Small, Mobile, Special-Purpose Robots

Gas Buffer Seal

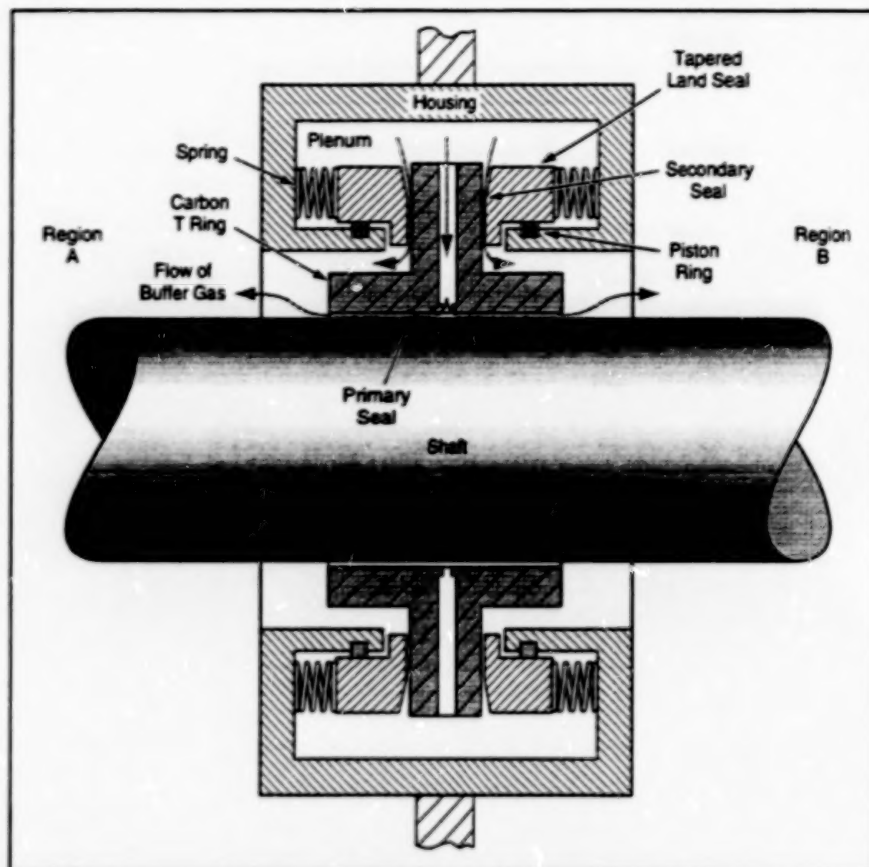
The buffer flow separates two gases that must not come into contact.

Lewis Research Center,
Cleveland, Ohio

The figure presents a simplified view of a shaft seal that provides a small flow of neutral buffer gas to prevent contact between different gases contained in two adjacent regions along the shaft. In the original application, the shaft couples a hydrogen-burning turbine with a high-pressure oxygen pump, and helium is used as the buffer gas to prevent hydrogen/oxygen contact along the shaft. Other potential applications could involve the use of helium or other buffer gases or liquids to prevent mixing of fluids or to prevent escape of process fluids that are poisonous, odorous, or harmful to equipment or to the environment.

The seal (see figure) is a combination of a primary and a secondary seal. The main structural component of the seal is a solid carbon ring with a T-shaped meridional cross section. The buffer gas flows from a plenum, through 36 equally circumferentially spaced narrow radial holes in the ring, to the clearance [a gap 2 to 3 mils (0.05 to 0.08 mm) thick] between the ring and the shaft. Upon reaching the shaft, the flow splits into two smaller flows in opposite directions along the shaft. The combination of the clearance and the split flow of buffer gas constitutes the primary seal.

The secondary seal is a pressure-assisted, fluid-film seal between T ring and a housing that bounds the plenum. This housing is shaped approximately as a hollow ring of rectangular meridional cross section. The fluid-film seal between the housing and the T ring is effected by two tapered land seals. The pressure of the buffer gas in the plenum pushes these seals toward the housing, forming a low-friction clearance with the T ring. The tapered land seals are also lightly spring-



The Leakage Flows of Buffer Gas in Narrow Clearances act as low-friction seals and maintain the required separation between different gases in regions A and B.

loaded to hold them in place before gas pressure is applied. The secondary seal is a low-friction seal that tolerates sliding between the T ring and the housing. Thus, the T ring is free to track the runout (if any) of the shaft.

This work was done by Wilbur Shapiro and Henry F. Jones, Jr., of Wilbur Shapiro & Associates, Inc., for Lewis Research

Center. Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16339.

Books and Reports

Flexible Actuators for Small, Mobile, Special-Purpose Robots

A report discusses flexible microactuators for a proposed generation of small, mobile, special-purpose robots. Aspects of this topic were discussed in two previous articles in *NASA Tech Briefs*: "Thin-Film, Light-Energized Bimorph Micro-

mechanical Actuators" (NPO-19607), Vol. 20, No. 8 (August 1996), page 11a and "Tetherless, Optically Controlled Nanorovers" (NPO-19606), Vol. 21, No. 3 (March 1997), page 92. To recapitulate: insectlike robots equipped with microsensors and/or micromanipulators are proposed for use in applications as diverse as remote exploration, surgery, and surveillance. These robots would move by the electronically and/or pho-

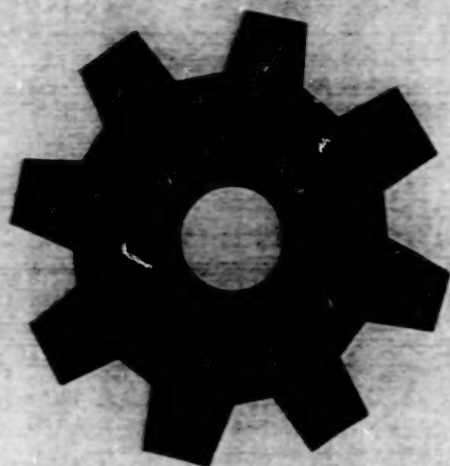
tonically controlled bending of flexible cantilever-beam bimorph microactuators (composites of thin piezoceramic films on strong polymeric substrates) that would be analogous to animal limbs except that they would not be jointed. The report emphasizes that in comparison with other actuators with equal areas, the proposed microactuators would offer high ratios of generated force to input power, and that unlike actuators

micromachined from silicon, the proposed microactuators would not be restricted by the clamping effects of substrates. The report reviews the state of the art, discusses the principles of operation and the rationale for using the

microactuators, describes potential applications, and proposes research to develop advanced piezoceramic materials for microactuation.

This work was done by Sarita Thekoor and Jim Cutts of Caltech for NASA's

Jet Propulsion Laboratory. To obtain a copy of the report, "Flexible Micro-Actuators for Advanced Mobility," see TSPs [page 1].
NPO-20019



Machinery

Hardware, Techniques, and Processes

- 35 Adaptive Performance Optimization of Transport Aircraft
- 36 Using a Jet Pump To Alter the Inlet Swirl of a Turbopump

Books and Reports

- 36 Development of Small, Mobile, Special-Purpose Robots

Adaptive Performance Optimization of Transport Aircraft

Control adjustments to obtain minimum drag are made automatically.

Dryden Flight Research Center,
Edwards, California

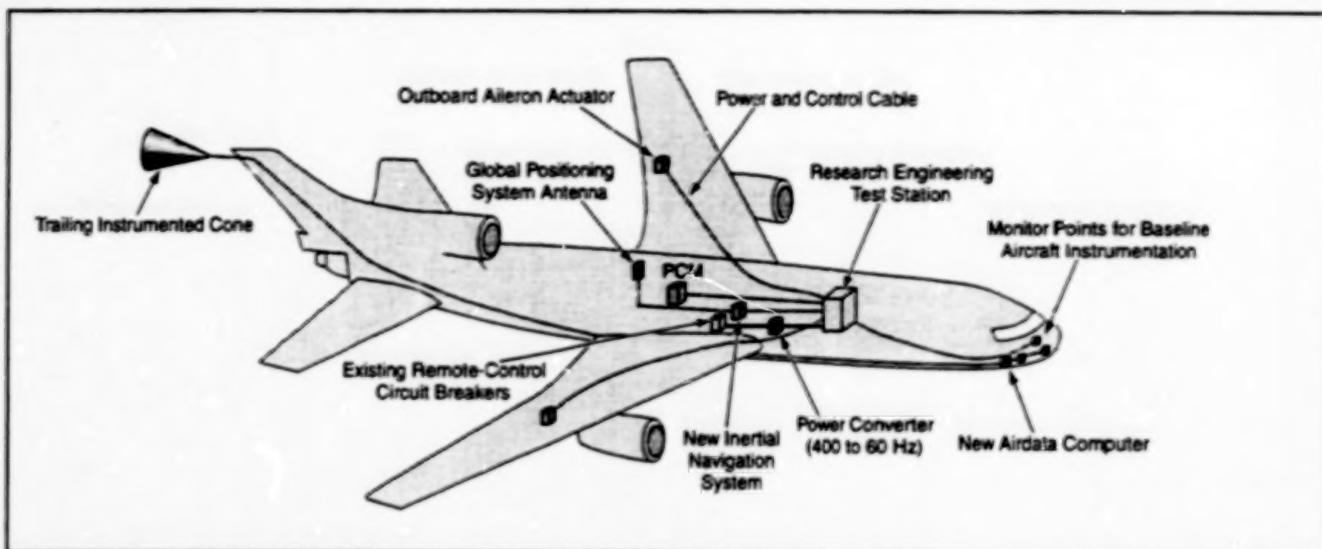


Figure 1. A Transport Airplane Was Modified for use in experiments on APO.

Adaptive performance optimization (APO) is an approach for improving aircraft performance without the need for extensive modifications of hardware. In this approach, one exploits existing redundant control-effector capabilities by providing for automatic reconfiguration of control-surface deflections to achieve a minimum-drag trim condition.

The application of adaptive performance optimization (APO) to transport aircraft, utilizing redundant control effectors, can be a significant factor for improving the profitability of airlines. For example, the use of APO to effect a 1-percent reduction in drag for the U.S. fleet of wide-body transport airplanes could result in savings of approximately \$140 million per year [assuming that fuel costs \$0.70/gallon (\$0.19/L)].

Preliminary design work has been performed for implementation of variable camber in transport airplanes, with APO serving as part of the basis of a new approach to actuation and control of wing trailing-edge control surfaces. The possibility of deriving a benefit from the application of APO to either a new full variable-camber design or to a retrofit to an existing transport airplane depends on the existence of a potential for optimization; in particular, it depends on the existence of a redundant control-effector capability (that is, more than one means of trimming out the forces and moments to obtain a steady-state flight condition). Most transport aircraft have significant capability in this area, though in some cases, minor modifications could be necessary. APO

addresses a systematic means of utilizing of this capability. Controls and/or variables that can potentially play a role in optimization of performance of current and future transport aircraft include elevator, horizontal stabilizer, outboard aileron, inboard aileron, flaps, slats, rudder, center of gravity, and differential thrust. The key technological challenge to in-flight optimization of performance of transport aircraft is identification of incremental drag to an accuracy better than 1 percent.

An L-1011 airplane has been modified for use in a NASA program of flight research in APO for transport airplanes. The modifications (see Figure 1) consist of (1) addition of a research engineering test station; (2) addition of an actuator (one on each wing) to drive the outboard ailerons symmetrically; (3) addition of an instrumented trailing cone to obtain true static pressure; (4) connecting into the basic airplane instrumentation system to obtain engine, control surface, and other measurements; (5) addition of an embedded navigation system with Global-Positioning System (GPS) and inertial-navigation subsystems; (6) addition of a state-of-the-art airdata computer; and (7) addition of a data-recording system.

In the cruise mode, the APC algorithm commands a smooth, long-period excitation of a redundant control surface — specifically, a symmetric excitation of outboard ailerons. The forced excitation is smooth enough and of sufficient duration that the mach- and altitude-hold autopilot

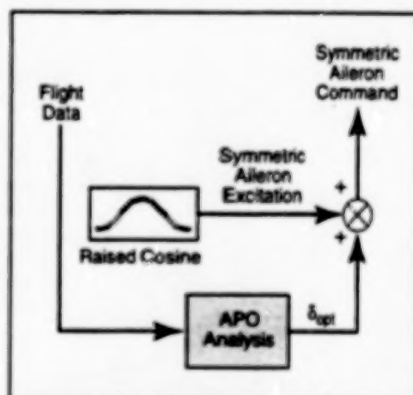


Figure 2. The APO Algorithm analyzes flight data and adjusts symmetric aileron deflection to minimize drag.

modes "mask" the quasi-steady pitching-moment drag changes that occur during maneuvers that involve changes in the throttle setting, stabilator angle, and/or angle of attack. The resultant data are analyzed to determine the minimum-drag configuration, and the redundant controller is configured appropriately (see Figure 2).

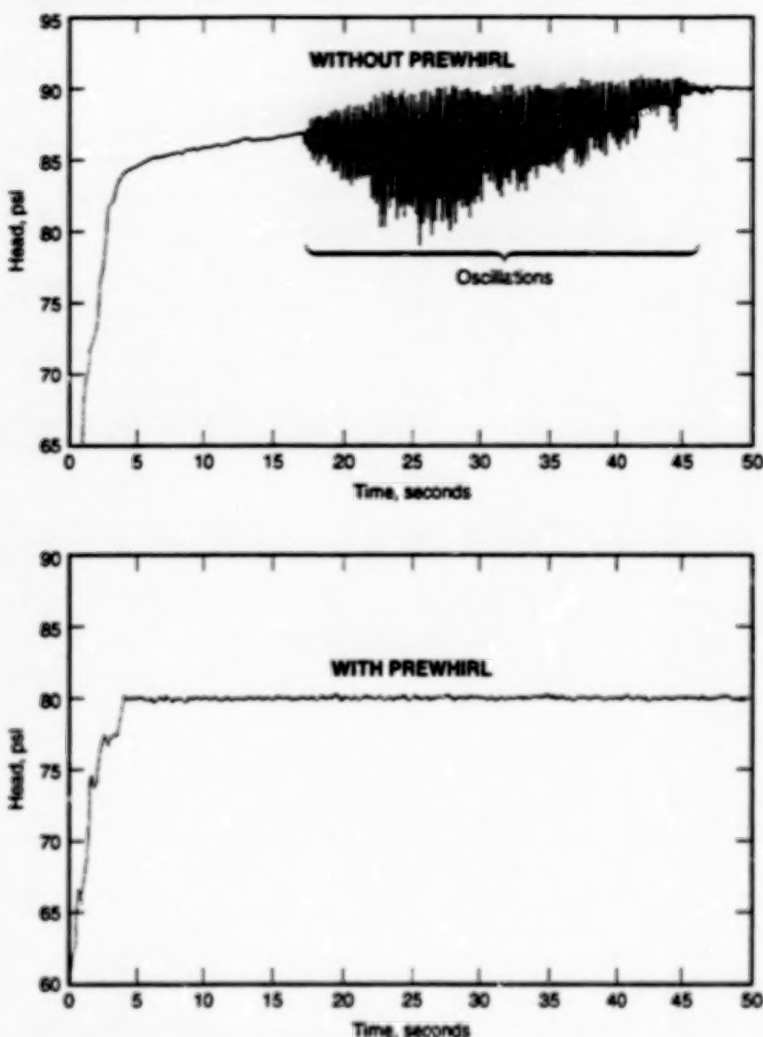
This work was done by Glenn B. Gilyard of Dryden Flight Research Center. Further information is contained in a TSP [see page 1].

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Technical Information Specialist, Dryden Flight Research Center; (805)258-3720. Refer to DRC-95-22.

Using a Jet Pump To Alter the Inlet Swirl of a Turbopump

With suitable design, turbopump oscillations can be suppressed.

Marshall Space Flight Center,
Alabama



Oscillations Were Eliminated by injection of high-pressure flow to introduce prewhirl into the inlet flow of a turbopump.

An analysis of empirical data on low-frequency oscillations in the inlet flow of a turbopump has led to the conclusion that these oscillations could be reduced or

eliminated with suitable design of a jet pump to alter the inlet swirl. The oscillations in question are of fluid-dynamic origin and occur in the absence of externally

supplied excitation, are related to cavitation, and are of approximately constant frequency and amplitude. They are undesired because they give rise to instabilities that can be transmitted to the thrust-chamber stage of the turbopump.

Heretofore, such oscillations have been suppressed by *ad hoc* measures determined by trial and error; e.g., incorporating holes into inducer blades, increasing inducer tip clearances, or prewhirl injection. The present concept involves a combination of (1) a more systematic approach in which one seeks to avoid the flow conditions that favor the oscillations and (2) recognition that jet pumps upstream of inducers or impellers have been found to increase the suction performances of turbopumps. Accordingly, one tries to suppress oscillations by designing either an axial jet pump or an angled-nozzle jet pump to improve suction performance and to alter the inlet flow conditions (in particular, the inlet swirl) in such a way and to such an extent as to prevent the oscillations.

Experiments have shown that the oscillations occur within restricted ranges of net positive suction head (NPSH), speed, flow rate, and angle of incidence of flow on inducer blades. Thus, according to the present concept, one could suppress the oscillations by, for example, designing a jet pump to inject prewhirl to bring the angle of incidence out of the range for oscillation at a given NPSH. The figure illustrates the results of an experiment in which oscillations in a liquid-oxygen turbopump were suppressed in this way.

This work was done by Sen Y. Meng and Laura A. Brozowski of Boeing North American, Inc., for Marshall Space Flight Center. Further information is contained in a TSP [see page 1].
MFS-30086

Books and Reports

Development of Small, Mobile, Special-Purpose Robots

A report presents a scenario for the proposed development of insectlike robots that would be equipped with microsensors and/or micromanipulators,

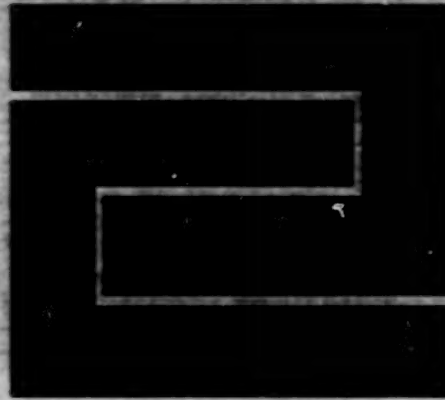
and would be designed, variously, to crawl, burrow, swim, fly, or hop, to perform specific tasks in fields as diverse as exploration, micropositioning, and surgery. In part, the report reiterates and extends previous discussions of this concept from a number of previous NASA Tech Briefs articles and supporting documents, including those mentioned in

NPO-20019 (page 31). One notable feature not mentioned previously is a proposed hierarchical scheme in which insectlike exploratory robots would communicate with fewer larger, more-complex robots, and so forth up a hierarchy to a central robot or instrumentation system. The report discusses the historical background of the concept, presents an

overview of the uses and functions of the robots, describes the objective and justification for a program of research and development, and summarizes the potential technological and economic advantages offered by the proposed robots. The report goes on to discuss the advanced fabrication, actuator, computer,

sensing, computing and power-supply technology that must be developed and refined to implement insectlike mobility and functionality for various robotic tasks. A list of tentative development goals is presented; the final goal in this list is the demonstration of an insectlike exploratory robot in the year 2001 and beyond.

This work was done by Smita Thakoor of Caltech for NASA's Jet Propulsion Laboratory. To obtain a copy of the report, "Insect-Explorer Technology Development: Exploration of New/Hazardous Territory," see TSPs [page 1].
NPO-20267



Fabrication Technology

Hardware, Techniques, and Processes

- 41 Two-Sided Tools for Layup of Composite Sandwich Panels
- 42 Vertical Centrifugal Investment Casting Machine
- 43 Fabrication of Thin-Film Type-S Thermocouples
- 43 Metal Gasket Bonded by Electrical Heating
- 44 Removable Fillers for VPS Fabrication of Closed Channels
- 45 Controlled-Oriented Short-Fiber Composite Bodies

Two-Sided Tools for Layup of Composite Sandwich Panels

Less floor space is needed for tooling for large panels.

Lyndon B. Johnson Space Center, Houston, Texas

A simple change in the design of tools used in manufacturing laminated-composite-material sandwich panels reduces the floor area needed to store the tools. To give meaning to a description of this modification, it is necessary to explain the basic function and original design of these tools: The basic function of such a tool is to provide a surface sized and shaped (possibly including a complex curvature) to match one of the two face sheets of the composite sandwich panel to be fabricated. A sheet of laminated composite material in uncured or partially cured form is laid up on the tool surface, then cured to form a face sheet (see Figure 1). The face sheet is then removed from the tool surface. The opposite face sheet is formed in the same manner on another tool, then the two face sheets are bonded to opposite faces of a honeycomb- or eggcrate-like core to form the composite sandwich panel.

Often, tools of this type have structures similar to those of the composite panels to be fabricated; the tools can include face sheets that define the tool surfaces and that are supported by honeycomb- or eggcrate-like structures. Often, the tools are even made of composite materials.

Each tool designed according to the original concept described thus far includes only one tool surface. The modified-tool concept calls for two tool surfaces for forming both face sheets of the composite sandwich panel that one seeks to fabricate. Like the panel itself, the tool of modified design features two face sheets (which define the two tool surfaces) bonded to opposite faces of a honeycomb- or eggcrate-like core (see Figure 2). To facilitate handling, the tool can be mounted in a steel frame; the mounting should be loose, with sufficient clearance to allow the tool to "float" in the frame to accommodate differential thermal expansion between the tool and the frame.

The biggest advantage of the two-sided tool design over the single-sided tool design is that twice as much mold-surface area is accommodated in the same floor area—an important consideration in the manufacture of large panels. In addition, the fabrication of two tool faces held on a common supporting structure involves less labor than does fabrication of two tool faces on individual supporting structures. The two-sided tool design could prove useful in the manufacture of a variety of curved composite-material sandwich parts; for example, boat hulls and outer shells of automobiles.

This work was done by David Attemir and Mike Fowler of Johnson Space Center. No further documentation is available. MSC-22725

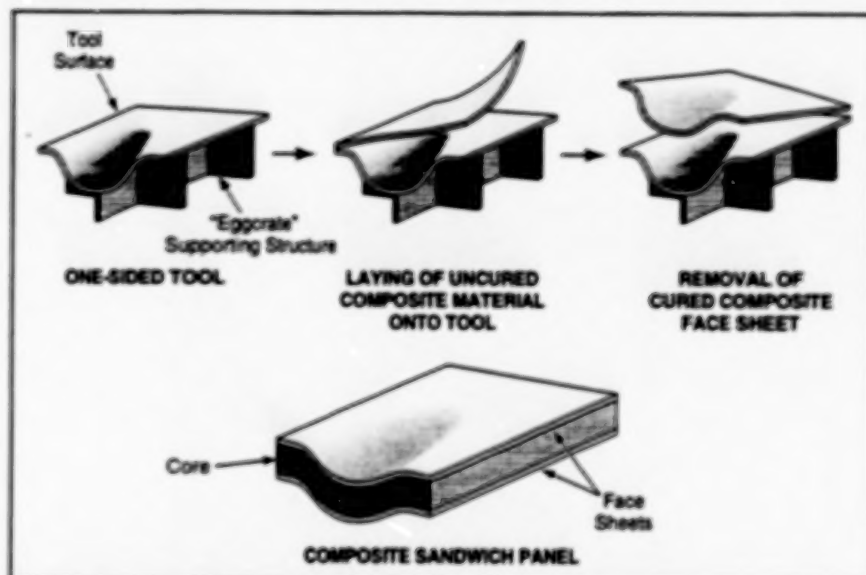


Figure 1. Each Face Sheet of a composite sandwich panel is formed by laying up and curing a sheet of laminated composite material on a tool surface that imparts the desired shape.

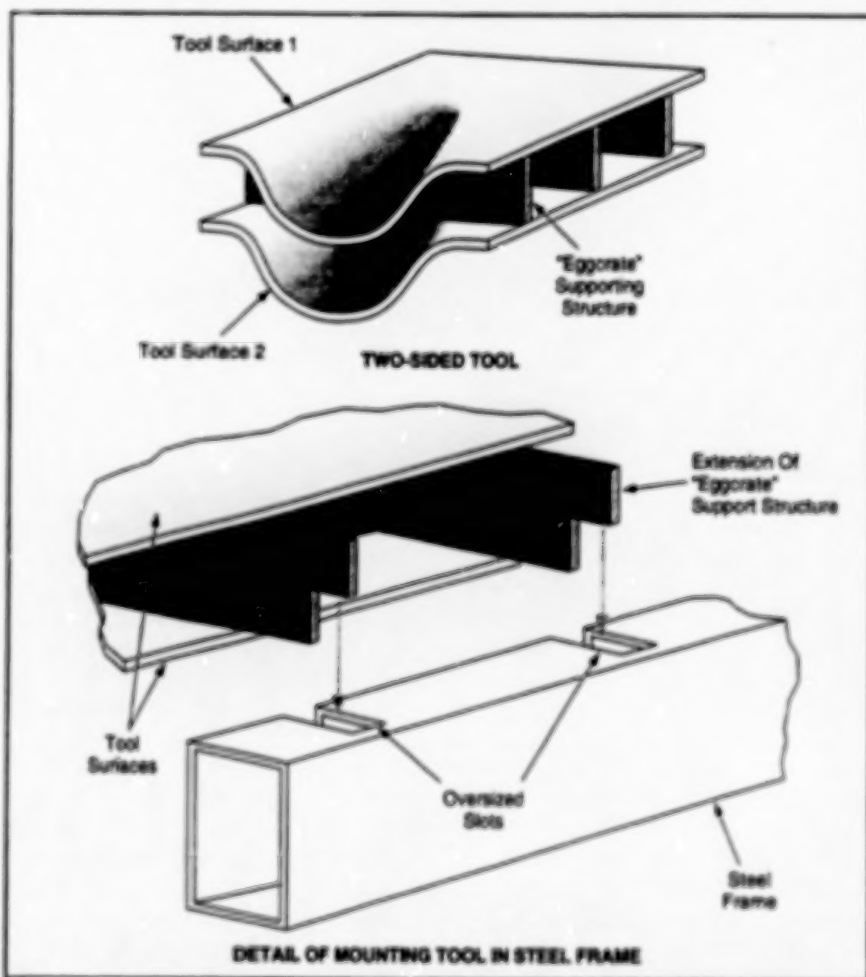
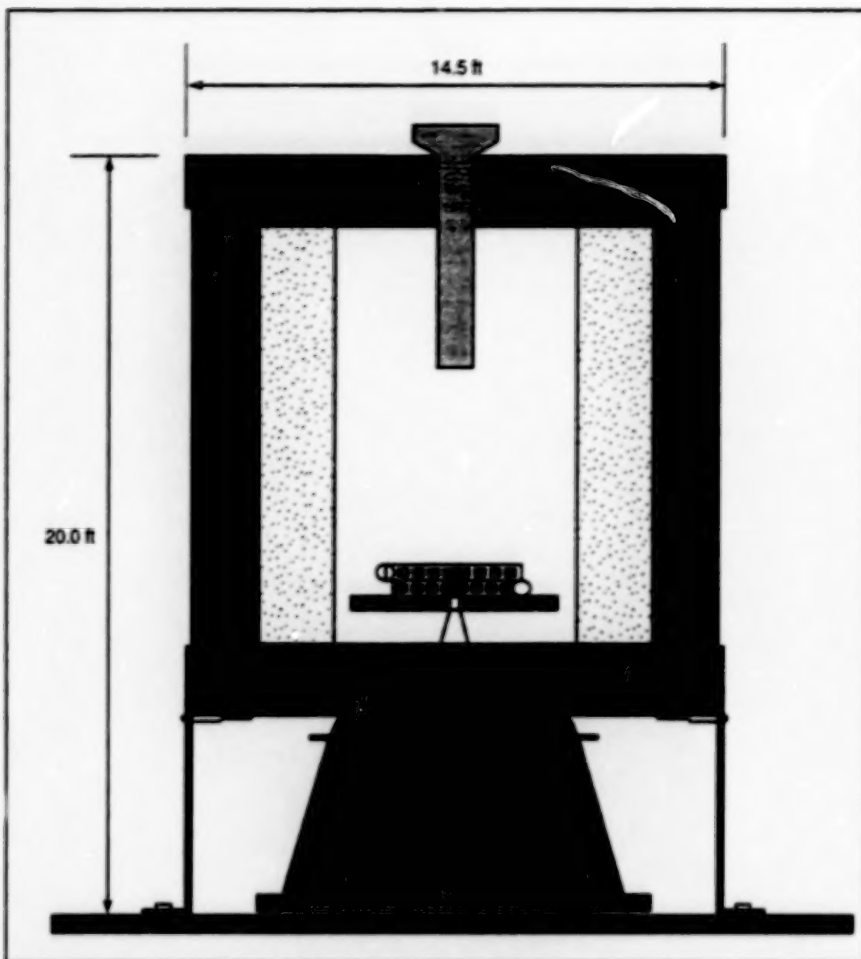


Figure 2. This Two-Sided Tool is similar to the one-sided tool of Figure 1, except that two tool faces are supported by a single structure. Thus, twice as much tool area is contained within the same floor area.

Vertical Centrifugal Investment Casting Machine

Improved design increases the strength of investment castings.

Marshall Space Flight Center,
Alabama



The Vertical Centrifugal Investment Casting Machine spins an axis symmetric shell about its own axis in a vertical orientation.

The need for improved investment castings at Marshall Space Flight Center's Rapid Prototyping Lab has led to the development of a simple machine for centrifugal investment casting of shells. This machine spins a radially symmetric shell about its own axis in a vertical orientation. This rotational process increases the strength of the investment casting by allowing the metal to move into even the most obscure crevices of the shell.

The major components of the vertical centrifugal investment casting machine are a funnel, a turntable with a clamping mechanism, an electric motor, exterior shells and supports, a base plate, two

semi-cylindrical ceramic heaters with insulation, a heat-conducting interior drip shield, and a heater control device with feedback from a thermocouple. Although not part of the machine, a digital stroboscope and an accelerometer with a temperature compensation and signal amplification circuit are used during the vertical centrifugal investment casting process.

The process of investment casting is not new. However, risers of novel designs were included in the vertical centrifugal investment casting machine to accommodate dynamics of fluids in a rotational environment. For example, risers used in static casting are usually

made funnel-shaped to assist foundry workers during metal-pouring processes. But a funnel-shaped riser increases the tendency for accelerated fluid to escape from the opening of the rotating shell. Therefore, for experiments conducted in the design of this machine, inverted funnel-shaped risers were attached to each shell. These inverted funnel-shaped risers provided back pressure to the spinning molten metal. The widest conical portions of the funnel-shaped risers also served as reservoirs for molten metal that escaped from a shell-molding cavity during centrifugal investment casting.

The process of dipping a wax pattern in a ceramic slurry and then applying a sand coat creates a shell with slight imbalances. When such a shell is rotated at high speed, these small imbalances can lead to significant vibrations and, consequently, a poor casting. The vibrations can also be hazardous.

To restore the center of gravity to the axis of rotation and thereby correct for these imbalances, a counterweight is put on the turntable. Holes around the perimeter of the turntable enable for the attachment of counterweights. For each shell being cast, it is necessary to test for vibrations, using a hand-held stroboscope, in order to determine the exact masses and locations of counterweights and the optimum rate of rotation.

Once the shell is properly balanced, the ceramic heaters and exterior shells are secured to the base plate. The shell is pre-heated, using a thermocouple to provide a temperature reading. Next, the heaters are turned off and the thermocouple removed. Rotation is begun immediately. Molten metal is poured into the funnel once full speed is reached. Within only a few seconds, the metal has been poured into the shell-molding cavity. After cooling, the machine is dismantled and the shell is extracted.

This work was done by Gary Lai and Floyd Roberts of Marshall Space Flight Center. Further information is contained in a TSP [see page 1].
MFS-31181

Fabrication of Thin-Film Type-S Thermocouples

These thermocouples can be used to measure surface temperatures.

Lewis Research Center,
Cleveland, Ohio

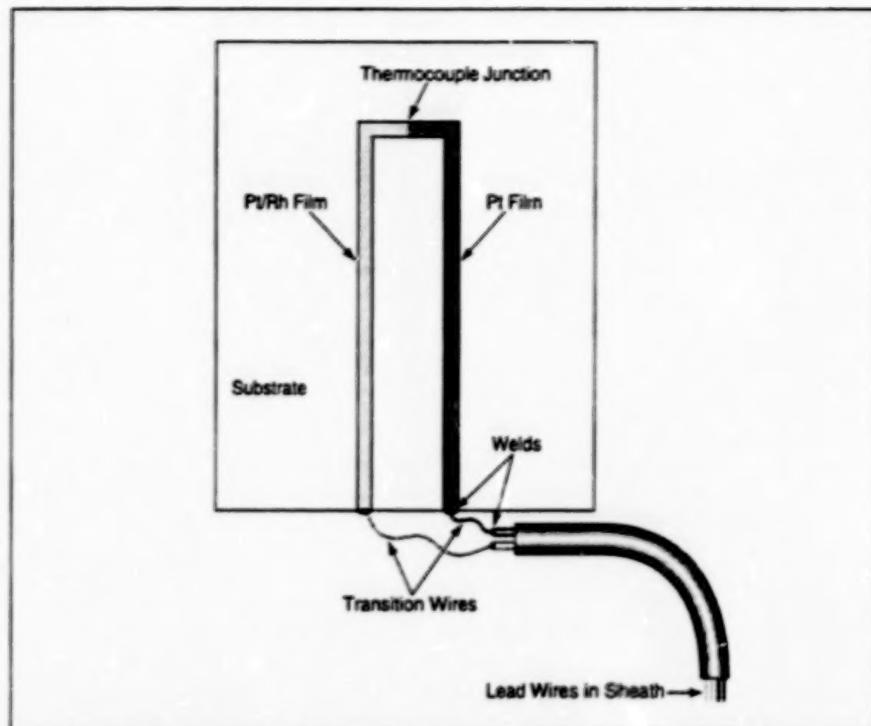
Processes for fabricating thin-film type-S thermocouples on metal and silicon nitride substrates (see figure) have been developed. (A type-S thermocouple comprises one leg made of platinum and the other leg made of an alloy of platinum with a rhodium content of 10 percent.) Thin-film type-S thermocouples can be used to measure temperatures on the surfaces of metal and ceramic components and are intended, especially, for use as monitoring and control sensors in the development and operation of advanced engines.

The fabrication processes involve numerous steps. Combining some steps for clarity, the processes can be described as follows:

The process for fabrication on a metal substrate begins with polishing and cleaning the substrate. The clean substrate is precoated (by vapor deposition) with NiCoCrAlY to a thickness between 50 and 120 μm . The precoated substrate is cleaned and oxidized to form an electric surface layer of $\alpha\text{-Al}_2\text{O}_3$.

A photoresist is applied and patterned with an opening for the Pt leg of the thermocouple, and the Pt leg is deposited by sputtering to a thickness between 2 and 3 μm . After removal of photoresist and further cleaning, a new photoresist mask for the Pt/Rh leg of the thermocouple is formed, then the Pt/Rh leg is deposited to a thickness of 2 to 3 μm . The second photoresist mask is removed, the workpiece is cleaned, and a protective overcoat of Al_2O_3 is deposited on vulnerable portions of the thermocouple legs to a thickness between 1.5 and 2.0 μm .

Transition Pt and Pt/Rh wires with a diameter of 3 mils ($\approx 76 \mu\text{m}$) are welded to the outer contact ends of the Pt and Pt/Rh thermocouple films, respectively. Then external 0.020- or 0.040-in. (0.5- or 1.0-mm)-diameter



A Thin-Film Type-S Thermocouple can be fabricated on a metal or silicon nitride substrate in a multistep process. The overcoat and the ceramic cement over welded transition wires is omitted to show the complete layout of thermocouple metal parts.

sheath lead wires of Pt and Pt/Rh, respectively, are welded to the outer ends of the Pt and Pt/Rh transition wires. The transition wires and their welded junctions are covered with a ceramic cement.

The process for fabrication on a silicon nitride substrate also begins with polishing. The polished substrate is thermally oxidized to form silicon dioxide and silicon oxynitride, then etched in hydrofluoric acid to remove the silicon dioxide and leave a layer of silicon oxynitride 60 to 100 $\text{\AA}$ thick. The remaining steps of forming the Pt and Pt/Rh legs, attaching wires, and protective overcoating are similar to those described

above for fabrication on a metal substrate, except an anneal is performed before attaching the transition wires.

This work was done by Raymond H. Niska, Nicholas F. Schmidt, and Joseph R. Hoge of Allied-Signal Aerospace Co. for Lewis Research Center. Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16437.

Metal Gasket Bonded by Electrical Heating

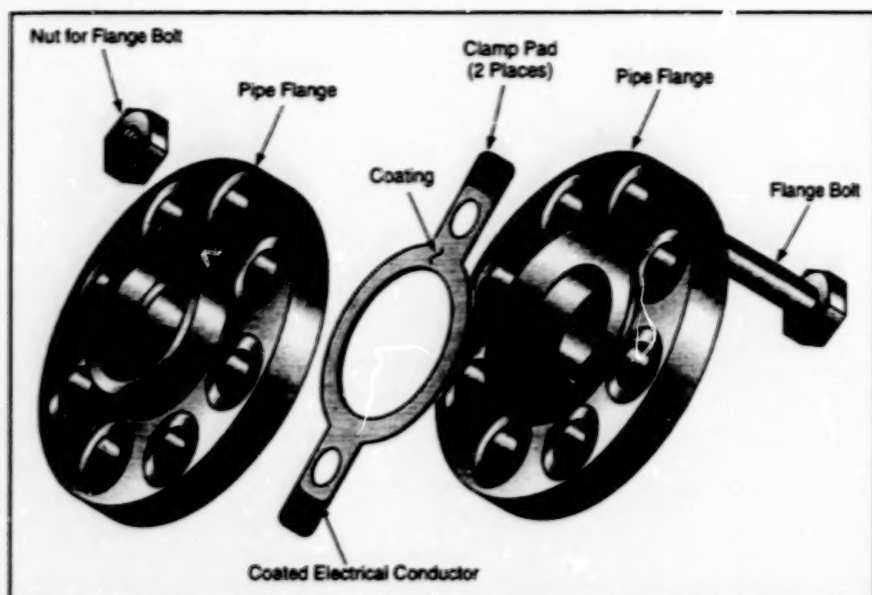
A weld-quality seal can be made without welding.

Marshall Space Flight Center, Alabama

An improved technique for sealing a joint in a fluid system involves the installation of a specially designed gasket in a thermal bonding process. The process results in a leak-free joint. Heretofore, joints

have been sealed, variously, by welding and by such mechanical means as lapping and the use of gaskets. It has been extremely difficult to make leak-free joints by mechanical means.

With respect to protection against leakage, sealing by the present improved technique is equivalent to welding. However, unlike in welding, there is no need for a certified welder or for full access



The Improved Sealing Technique Has Gaskets and Flanges that are assembled and clamped together. Then the gasket is heated by passing electrical current through its substrate to melt the coating and thereby form bonds with the flanges.

to the joint to be sealed. The time and cost of assembling and sealing a joint by the present technique is less than the process time and cost of welding a comparable joint. The present improved sealing technique and gasket design make it possible

to achieve tight seals, without need for lapping, between flanges and flat-faced coupling surfaces in fluid systems. This type of sealing technique is also a candidate for replacing currently used engine cylinder head gaskets.

The basic component used in the present technique is a flat, electrically conductive gasket, usually with a hole in the center. The gasket comprises an electrically conductive substrate coated on both sides with a low-melting-temperature metallic alloy. When properly activated, the gasket bonds to the surfaces of flanges or other surfaces of the fluid-system joint to be sealed.

The sealing process is simple. Once the gasket is inserted between the joint interfaces (see figure) and secured, electrical leads from a power source are attached to opposite ends of the gasket. When electrical energy is supplied via the leads, the coating melts, creating bonds at the interfaces. To unseal the joint, one simply removes the flange bolts and reheats the gasket.

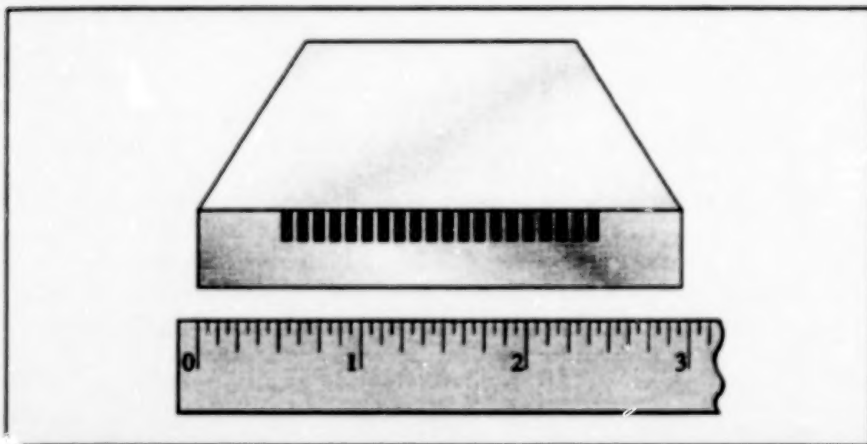
This work was done by Melvin A. Bryant III of Marshall Space Flight Center. Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 1]. Refer to MFS-31175.

Removable Fillers for VPS Fabrication of Closed Channels

These ceramic materials can withstand high processing temperatures.

Marshall Space Flight Center,
Alabama



Channels in a Solid Metal Plate were formed by VPS of metal onto ceramic-filled grooves and adjacent areas of the top surface. In the initial experiments on this process, the plates and the deposited material were made of copper.

An improved process has been devised for making closed channels (e.g., coolant channels) in a heat-exchanger liner or a similar metal object. The process involves the following steps: First, grooves destined to become closed channels are machined into the object from one surface. Next, a

ceramic filler material is troweled into the grooves, made flush with the surface, and allowed to harden by evaporation of water. Next, vacuum plasma spraying (VPS) is used to deposit metal on the exposed metal and filler surface areas to cover the grooves and thereby form closed channels

(see figure). Finally, the filler material is removed from the channels. This process satisfies a need for making the channels at lower cost and in less time than is possible by an older process in which the grooves are filled with wax, then a thin layer of copper is electroplated on the exposed metal and wax surface areas, then a thick nickel structural jacket is deposited on the copper.

The success of the process depends on the proper choice of the filler material. A ceramic is attractive for this purpose because, unlike wax, it can withstand the VPS process temperature. The filler is required to be sufficiently fine-grained to enable the deposited metal to have a sufficiently smooth surface [32 μ m. (0.8 μ m) in the original application for which the process was devised]. The filler is also required to be removable after VPS.

The ceramic filler materials found to be most suitable are mixtures of silica powder with water and various proportions of sodium silicate or colloidal silica, which serve as binders. A third binder made of a

cellulose ether compound can be used in combination with either of the other two binders to tailor the viscosity of the overall mixture for both troweling the filler into the channels and removing the filler after VPS.

It is desirable to facilitate and accelerate post-VPS removal of the filler by providing flow paths for flushing the filler out of the channels. For this purpose, before the filler material is troweled into the channels,

a yarn or rope made of a polymeric material is placed in the bottom of each groove, extending beyond the ends of the groove. The polymeric material should be either one that decomposes and shrinks at the high VPS process temperature or else one that can be pulled out after hardening of the filler or after VPS. After VPS, the filler can be flushed out of the completed channels; for example, by alternat-

ing flows of pressurized water and a hot NaOH solution.

This work was done by D. Andy Hissam and Frank Zimmerman of **Marshall Space Flight Center** and William M. Davis, Philip Krotz, Yoon K. Liaw, Peter Oelgoet, and Heather Sanders of Rockwell International Corp. Further information is contained in a TSP [see page 1].
MFS-30124

Controlled-Orientation Short-Fiber Composite Bodies

Microstructurally controlled composite properties mimic biomaterials.

Marshall Space Flight Center,
Alabama

A technique for depositing materials into position using a positive-displacement extruder to build up a body has been developed. This technique also includes a process to prepare composite materials through a solid free-body forming process containing directionally aligned short-fiber reinforcement and ceramic-particulate reinforcement (of which at least a portion is derived from an alkoxide precursor).

With this newly developed technique, the matrix resin contains fiber and/or high loadings of ceramic particulate (precursor). The fiber reinforcement is oriented by shear stresses in the extrusion process. The matrix resin has very low shrinkage and is capable of being cured in a short time after deposition.

This new technique for depositing materials into position uses a stereolithography system, comprised of a table and computer-controlled gantry system, a vertical slide and resin dispenser, and a heated platen. A computer-aided-design package is used to make a virtual image of a solid body. The computer translates the

virtual image into motion instructions, which are, in turn, converted to indexer commands and motions of the resin dispenser. The resin dispenser extrudes resin through a needle while sweeping out a path to build up the solid body on the heated platen. The resulting part is thermally cured during or after deposition.

Composite resin systems were developed for this process based on specialty acrylic monomers. These monomers combine short chains of structural polymers with acrylate end groups. Upon curing, the acrylate end groups join, forming a polymer with properties similar to the structural polymer. A cross-linking agent was used to promote rapid curing. This resin system produces a tough, strong polymer within several minutes when heated, with very low shrinkage upon curing.

An advantage of this resin deposition system is that it has a low viscosity. A viscosifier is required to lay the material up. It was found that the addition of 1.66 volume percent fumed silica provided sufficient viscosity so that beads of the material could be neatly laid up. The viscosified

resin was reinforced with chopped carbon or glass-fiber and ceramic particulate.

This solid free-body-forming process was used to produce controlled-alignment fiber-reinforced composites. Also, highly loaded ceramic particulate reinforced composites were prepared using this method.

Flexure testing of composite specimens showed the properties to be quite respectable when compared to traditional structural polymer materials. These tests also demonstrated that the specimens were far better than the materials that are currently produced by other solid free-body-forming technologies.

This work was done by Kevin Stuffle, Gabriel Chambers, John O'Kelly, John Lombardi, Anthony C. Mulligan, and Paul Calvert of Advanced Ceramics Research, Inc., for **Marshall Space Flight Center**. Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 1]. Refer to MFS-26445.



Mathematics and Information Sciences

Hardware, Techniques, and Processes

- | | |
|----|--|
| 49 | Training of Neural Networks by Modified Taguchi Techniques |
| 50 | LTI Approach to Adaptive Narrow-Band Feedforward Control |
| 51 | Improved Design of Adaptive Feedforward Tracking Systems |
| 51 | Expressing Object-Oriented Concepts in Fortran 90 |
| 52 | Software for Assessing Effects of Designs on Operations |

Training of Neural Networks by Modified Taguchi Techniques

Neural networks learn faster than they do with gradient-descent techniques or genetic algorithms.

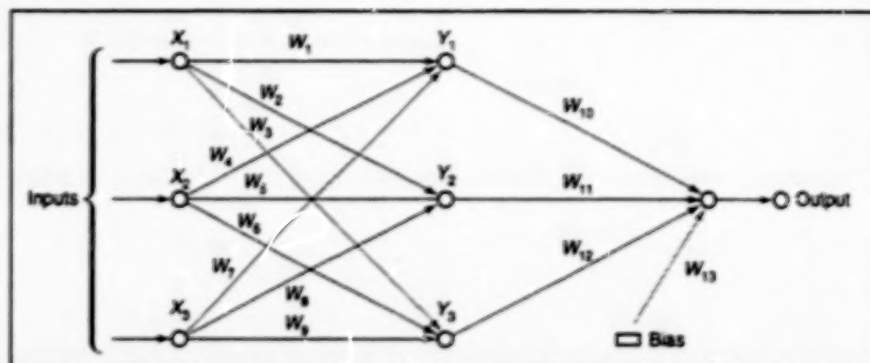
NASA's Jet Propulsion Laboratory,
Pasadena, California

Modified Taguchi techniques of robust design optimization are used in an innovative method of training artificial neural networks — for example the network shown in the figure. As in other neural-network-training methods, the synaptic weights (strengths of connections between neurons) are adjusted iteratively in an effort to reduce a cost function, which is usually the sum of squared errors between the actual network outputs and the prescribed (correct) network outputs for training sets of inputs. However, this method offers advantages over older methods, as explained below.

Heretofore, the most popular neural-network-training methods have been based, variously, on gradient-descent (GD) techniques or genetic algorithms (GAs). GD techniques are local search/optimization techniques; in a typical case, a GD technique leads to a local minimum of the cost function, which may not be the desired global minimum. Moreover, GD learning is slow, typically requiring thousands of iterations. GA learning involves global searches but is also slow, typically requiring hundreds of generations with hundreds of individuals in the population. The present innovative method involves global searches and enables a neural network to learn much faster (equivalently, in fewer iterations) than do GD- and GA-based methods.

In the present method, each of the N synaptic weights is treated as one of N design parameters to be optimized by Taguchi techniques. At each iteration, a number, M , of trial network designs are considered. In each design, each parameter is set at one of three distinct arbitrary levels. The various designs considered at each iteration are thus represented by M sets of N parameters each, each set being a distinct combination of the three levels. The ensemble of all M trial designs considered at each iteration can thus be represented by an $N \times M$ rectangular array. For example, the table shows an array of $M = 27$ trial sets of $N = 13$ parameters each for the neural network illustrated in the figure.

The cost is computed for each trial design. For each parameter, one computes three different cumulative costs, each comprising the sum of all costs for one of the three parameter levels. The three cumulative costs are compared. Then the search range for the parameter is



This Representative Neural Network contains seven neurons connected via 13 synaptic weights W . The output of one typical node is given $Y_i = f(W_i X_1 + W_i X_2 + W_i X_3)$, where $f(x)$ is a sigmoidal nonlinear function that could be, for example, $(1 + e^{-x})^{-1}$.

Inputs			Output											Cost
X_1	X_2	X_3	O											
0	0	0	0.2870											
0	0	1	0.3375											
0	1	0	0.3766											
1	0	0	0.2654											
1	0	1	0.3139											
1	1	0	0.3044											
1	1	1	0.3553											

Trial Design	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}	W_{12}	W_{13}	Cost
1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0.19
2	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0.26
3	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1	2.97
4	-1	0	0	0	-1	-1	-1	0	0	0	1	1	1	2.18
5	-1	0	0	0	0	0	0	1	1	1	-1	-1	-1	0.28
6	-1	0	0	0	1	1	1	-1	-1	-1	0	0	0	0.07
7	-1	1	1	1	-1	-1	-1	1	1	1	0	0	0	0.84
8	-1	1	1	1	0	0	0	-1	-1	-1	1	1	1	1.75
9	-1	1	1	1	1	1	1	0	0	0	-1	-1	-1	0.45
10	0	-1	0	1	-1	0	1	-1	0	1	-1	0	1	1.20
11	0	-1	0	1	0	1	-1	0	1	-1	0	1	-1	0.00
12	0	-1	0	1	1	-1	0	1	-1	0	1	-1	0	0.35
13	0	0	1	-1	-1	0	1	0	1	-1	1	-1	0	0.07
14	0	0	1	-1	0	1	-1	1	-1	0	-1	0	1	0.76
15	0	0	1	-1	1	-1	0	-1	0	1	0	1	-1	0.27
16	0	1	-1	0	-1	0	1	1	-1	0	0	1	-1	0.08
17	0	1	-1	0	0	1	-1	0	1	1	-1	0	0	1.12
18	0	1	-1	0	1	-1	0	0	1	-1	-1	0	1	0.10
19	0	-1	1	0	-1	1	0	-1	1	0	-1	1	0	0.26
20	1	-1	1	0	0	-1	1	0	-1	1	0	-1	1	1.47
21	1	-1	1	0	1	0	-1	1	0	-1	1	0	-1	0.04
22	1	0	-1	1	-1	1	0	0	-1	1	1	0	-1	0.39
23	1	0	-1	1	0	-1	1	1	0	-1	-1	1	0	0.10
24	1	0	-1	1	1	0	-1	-1	1	0	0	-1	1	0.87
25	1	1	0	-1	-1	1	0	1	0	-1	0	-1	1	0.12
26	1	1	0	-1	0	-1	1	-1	1	0	1	0	-1	0.02
27	1	1	0	-1	1	0	-1	0	-1	1	-1	1	0	0.75

An Array of Parameters comprising 27 sets of synaptic weights represents the trial designs of the network on the first iteration. The costs for the sets of training inputs and outputs are then analyzed according to the procedure described in the text to shift and narrow the search ranges of the parameters on the next iteration.

narrowed and is shifted toward whichever level gave the lowest cumulative cost; that is, three shifted, more-closely-spaced levels of the parameter are chosen for the trial designs on the next iteration.

The process is repeated until the parameters converge on values that make the

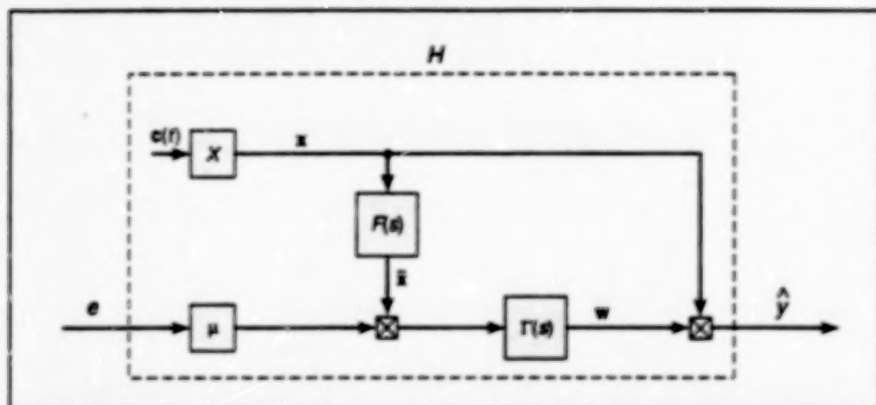
cost acceptably small. Typically, the search range for each parameter can be narrowed by half on each iteration, so that the intervals containing the solution can shrink by a factor of about 10^3 in only ten iterations. Thus, learning time is shortened considerably, relative to GD- and GA-based methods.

This work was done by Julian O. Blosiu and Adrian Stoica of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20018

LTI Approach to Adaptive Narrow-Band Feedforward Control

A necessary and sufficient condition for closed-form LTI representation has been discovered.

NASA's Jet Propulsion Laboratory,
Pasadena, California



The Operator H represents the mapping from the error signal e to the output in an adaptive system with harmonic regressor x , adaptation law governed by $\Gamma(s)$, and regressor filter $F(s)$.

A unified theory of linear time-invariant (LTI) representations has been developed for use in the analysis and design of adaptive, narrow-band, feedforward controllers for systems characterized by harmonic regressors (the term "harmonic regressor" is defined below). Such controllers are used, for example, to suppress harmonic noise and vibrations; the basic idea is to track disturbance tones actively and "notch" them by use of high-gain feedback to achieve large attenuation. The LTI approach embodied in the unified theory makes it possible to apply established LTI theoretical concepts to the adaptive-feedforward-control design problem, and thus to design stable, high-performance controllers while avoiding the complexities and risks associated with nonlinear and/or time-varying control loops.

It is necessary to explain some mathematical terms as a prerequisite to a summary of the unified theory. The figure schematically illustrates the relationships among the terms.

As part of the control problem, one seeks to obtain an estimate, $\hat{y}$, of some signal $y(t)$, where (t) signifies dependence on time. One constructs $\hat{y}$ as a linear combination of the elements of a regressor vector $x(t)$; namely, $\hat{y} = w(t)^T x(t)$, where

T denotes the matrix transpose and $w(t)$ is an N -dimensional parameter vector that is "tuned" in real time via an adaptation algorithm, the basic equation of which is described in the paragraph after the next one.

A system of the type to which this analysis applies is characterized by a harmonic regressor, among other things. A harmonic regressor is given by $x = Xc(t)$, where X is an N -by- $2m$ matrix and $c(t)$ is a $2m$ -dimensional vector of paired sinusoids and cosinusoids of arbitrary frequencies; namely,

$$c(t) = [\sin(\omega_1 t), \cos(\omega_1 t), \dots, \sin(\omega_m t), \cos(\omega_m t)]^T.$$

The regressor vector x is filtered through $F(p)$ to obtain $\hat{x}$. The filtering operation is represented by

$$\hat{x} = F(p)[x],$$

where p denotes the differential operator (replacing the Laplace s). The basic equation of the algorithm is

$$w = \mu \Gamma(p)[\hat{x}(t)e(t)],$$

where $\mu > 0$ is an adaptation gain, $e(t)$ is an error signal, $\Gamma(p)[\cdot]$ denotes a filtering operation in the same way that $F(p)[\cdot]$ above denotes a filtering operation, and $\Gamma(p)$ is a multivariable LTI transfer function of the designer's choosing, representing the desired adaptation law.

Taken together, the foregoing equations define an open-loop mapping from the error signal e to the estimated output $\hat{y}$. The mapping is represented by $\hat{y} = H[e]$, where H denotes the mapping operator. In general, H is a linear time-varying (LTV) operator, and this is where the unified theory makes a major contribution: The theory includes a theorem that provides a necessary and sufficient condition under which the overall effect of H can be represented exactly by an LTI operator, even though H may include time-varying elements. The condition is a result of the modulation and demodulation properties of products of the sinusoids contained in the harmonic regressors. The condition, called the "X-orthogonality" (XO) condition, is that the elements of X must be chosen so that $X^T X$ is a block-diagonal matrix consisting of 2×2 matrices proportional to positive identity matrices. When the XO condition is satisfied, the LTI representation is specified by a closed-form analytic expression.

The theory is characterized as "unified" because it produces, as special cases, all known instances of LTI adaptive feedforward systems previously reported in the literature. The theory generalizes the previous results by showing this class of LTI adaptive systems to be considerably larger than it was known to be. The theory has also been specialized to adaptive systems, the regressors of which are formed by filtering signals through tapped delay lines (TDLs). TDLs can be implemented easily and are used in diverse adaptive signal-processing applications. It has been shown (under mild conditions) that an adaptive system becomes asymptotically LTI as the number of taps in the TDL is increased.

This work was done by David S. Bayard of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20184

Improved Design of Adaptive Feedforward Tracking Systems

Performances can be enhanced, without need for additional hardware.

NASA's Jet Propulsion Laboratory,
Pasadena, California

An improved method of analysis and design offers the potential to enhance the performances of adaptive feedforward tracking systems. The method can, in principle, make it possible to increase such performance measures as rates of convergence and noise-cancellation ratios, without need for additional hardware. The method is applicable to communication systems, adaptive equalizers, adaptive systems for canceling noise from machinery, advanced vibration-suppressing systems, and echo-canceling systems. The method is particularly significant for overparameterized adaptive feedforward systems, which are very important in practice; they are used to ensure high-performance "tuning" of key signals in a wide range of terrestrial and outer-space applications, including the ones listed above.

It is necessary to explain some mathematical terms as a prerequisite to a summary of the improved method. In some respects, this explanation resembles the one in the preceding article, "LTI Approach to Adaptive Narrow-Band Feedforward Control" (NPO-20184); however, there are some differences, making it necessary to give a separate explanation here.

As before, one seeks to obtain an estimate, $\hat{y}$, of some signal $y(t)$, where (t) signifies dependence on time. One constructs $\hat{y}$ as a linear combination of the elements of a regressor vector $\mathbf{x}(t)$; namely, $\hat{y} = \mathbf{w}^T \mathbf{x}(t)$, where T denotes the matrix transpose and $\mathbf{w}(t)$ is an N -dimensional parameter vector that is "tuned" in real time via an adaptation algorithm, the basic equation of which is described below. The regressor vector is given by $\mathbf{x} = \mathbf{X}\mathbf{e}(t)$, where $\mathbf{X}$ is an N -by- n matrix and $\mathbf{e}(t)$ is as described below. A sys-

tem of the type to which the present analysis applies is one for which $N > n$; this is what is meant by "overparameterized" in the present context.

One constructs a suitable stable time-domain filter operator $F(p)$, where p denotes the differential operator (replacing the Laplace s for all time-domain interpretations). The regressor vector $\mathbf{x}$ is filtered through $F(p)$ to obtain $\tilde{\mathbf{x}}$. The filtering operation is represented by

$$\tilde{\mathbf{x}} = F(p)[\mathbf{x}].$$

The basic equation of the adaptation algorithm is

$$\dot{\mathbf{w}} = \mu \Gamma(p)[\tilde{\mathbf{x}}(t)\mathbf{e}(t)],$$

where $\mu > 0$ is an adaptation gain, $\mathbf{e}(t)$ is an error signal, $\Gamma(p)[\cdot]$ denotes a filtering operation in the same way that $F(p)[\cdot]$ above denotes a filtering operation, and $\Gamma(p)$ is a multivariable LTI transfer function of the designer's choosing, representing the desired adaptation law.

The vector $\mathbf{e}(t)$ is not the same as in the preceding article. Instead, $\mathbf{e}(t)$ in this case is an n -dimensional vector of piecewise-continuous signals that satisfies a condition called the "persistent excitation" (PE) condition, defined as follows: Let there be positive constants β_1 , β_2 , and T_0 , and a suitably dimensioned identity matrix, $\mathbf{I}$, such that

$$\beta_1 \mathbf{I} \leq \int_t^{t+T_0} \mathbf{e}(\tau)\mathbf{e}^T(\tau) d\tau \leq \beta_2 \mathbf{I}$$

for all $t \geq 0$. If any signal vector $\mathbf{e}(t)$ satisfies these criteria, it is said to be persistently exciting (PE) with bounds (β_1, β_2, T_0) . This completes the explanation of terms.

In the theoretical analysis on which the improved method is based, attention is focused on two matrix products: the confluence matrix (defined as $\mathbf{X}^T\mathbf{X}$) and the

autocorrelation matrix (defined as $\mathbf{X}\mathbf{X}^T$). This analysis reveals that the older methods based on the autocorrelation matrix and associated PE conditions are overly stringent for ensuring exponential convergence of the tracking error in an overparameterized adaptive feedforward system. Indeed, when an adaptive system is overparameterized, the PE condition is never satisfied, and therefore the older methods do not provide any clue as to the performance of the final adaptive design, much less provide guidelines on how to improve performance.

The analysis reveals, further, that if the confluence matrix is positive definite, then the adaptive feedforward operator H from the error e to the estimate is input-output equivalent to an adaptive system with a PE regressor; this implies that the tracking-error convergence is exponential for a large class of overparameterized adaptive feedforward systems. Thus, the positive-definiteness condition for the confluence matrix, which is easily satisfied, supplants the positive-definiteness condition for the autocorrelation matrix, and thus constitutes the theoretical basis of the improved method. The analysis also shows that the only penalties for overparameterization are that (1) the optimal exponential rate of convergence of tracking error is degraded by the condition number of the confluence matrix and (2) the parameter errors converge exponentially on a reduced subspace rather than over the entire space.

This work was done by David S. Bayard of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20183

Expressing Object-Oriented Concepts in Fortran 90

Object-oriented techniques could prove advantageous in writing complex Fortran-based scientific programs.

NASA's Jet Propulsion Laboratory,
Pasadena, California

A methodology for object-oriented programming in Fortran 90 has been developed. The methodology provides for emulation of the most important object-oriented concepts of C++; namely, classes (including abstract data types, encapsulation, and function overloading), inheritance, and dynamic dispatching. Previously, object-oriented programming in Fortran 90 was not considered possible.

This methodology makes the capabilities afforded by object-oriented techniques available to developers of complex Fortran-based scientific programs; thus, it becomes possible to combine some of the power and flexibility of C++ with the maturity and established scientific-computing capability of Fortran. An important advantage of this methodology is that Fortran programmers need not learn a

new, complex language — viz. C++.

The most fundamental concept in C++ that must be implemented in Fortran 90 is the concept of classes. Each class contains a distinct data type and the procedures that can be performed by the class. The elements (or components) of the data type are the class data members, and the procedures are the class member functions (or methods). In Fortran 90, one

defines a class as a module that contains exactly one abstract data type (called a "derived type") and the procedures that work exclusively on that type. A module in Fortran can also contain data that correspond to static class members in C++.

Another C++ concept that is essential to object-orientation and that must be implemented by hand in Fortran 90 is that of inheritance. Inheritance makes it possible to create a hierarchy of classes in which a base class contains the common properties of the hierarchy and derived classes can modify and specialize these properties. A derived class contains all the class data members of the base class and can add new class data members. Further, a derived class contains all the class member functions of the base class and can modify these functions or add new ones.

A third important C++ concept that must be implemented manually in Fortran 90 is that of dynamic dispatching or run-time polymorphism. By virtue of inheritance, a single method name can be made to respond differently to different objects in an inheritance hierarchy. Dynamic dispatching enables a single object name to refer to any member of an inheritance hierarchy and enables a procedure to resolve, at run time, which object is the referent. This ability is useful because

it enables one to write a generic program for a whole class of related objects, yet make the program behave differently, depending on which object is in use.

To implement dynamic dispatching in Fortran 90, it is necessary to construct two features: (1) a pointer object that can point to any member in an inheritance hierarchy and (2) a dispatch mechanism (or method lookup) that can select, on the basis of the class referred to in the pointer object, the appropriate procedure (or method) to execute. In C++, these features are incorporated automatically by use of virtual functions. In Fortran 90, they are constructed by implementing a subtype class. Although the details of dynamic dispatching are thereby exposed to the programmer, they can be hidden from the procedures that make use of the subtype class, as in C++.

Multiple inheritance in C++ enables one to create composite classes that have the properties of their bases classes. In Fortran 90, one can implement a composite class by including the base classes as components in a module, along with the USE operator to bring the base classes into scope.

Unlike in C++, templates and parameterized types are not supported in Fortran 90, and no effective way to emulate them has been found. A Fortran 90 program-

mer must explicitly provide some features that are automatically available in C++. Fortran 90 allows only a limited number of operators to be overloaded.

In efforts to write object-oriented plasma-simulation computer codes in both Fortran 90 and C++, each of these languages was found to offer both advantages and disadvantages, some in addition to those mentioned above. In the C++ version of the code, it was necessary to create special classes to utilize self-describing multidimensional arrays, which were automatically available in Fortran 90. On the other hand, it was necessary to create special subtype classes in Fortran 90 to emulate the dynamic dispatching that was automatically available in C++. Because type checking in Fortran 90 was stricter than in C++, more errors were caught by the compiler and debugging proceeded more quickly. It was necessary to write more code in Fortran 90. The execution time for the Fortran 90 version was about half that of the C++ version.

This work was done by Viktor K. Decyk and Charles D. Norton of Caltech and Boleslaw K. Szymanski of RPI for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP [see page 1].
NPO-20180

Software for Assessing Effects of Designs on Operations

Assessments can be performed quickly with powerful software tools and an extensive data base.

John F. Kennedy Space Center,
Florida

The Operations Impact Assessor (OIA) computer program facilitates rapid assessment of the effects of designs of spacecraft on spacecraft-processing operations at a launch site. OIA is a user-friendly, object-oriented, artificial-intelligence application program that features model-based reasoning and scheduling of discrete events.

The OIA enables the user to quickly develop a semantic model of a conceptual launch vehicle and its processing at a launch site to assess the effects of various elements of the design of the vehicle on the processing operations. The assessments can include evaluations of operability and processing requirements pertaining to such things as ground support equipment, utilization of facilities, labor, and processing schedules.

The use of the OIA proceeds in three stages: construction of a model of the launch vehicle, development of a model of process flow, and generation of an operational time line. The OIA consists of three

major components — intelligent assistants, the knowledge base, and utilities. The combination of these components provides an integrated operations-modeling environment. The OIA exploits an object-oriented frame system to store a model of the vehicle, resources, attributes, and schedules. Following a model-view-controller approach, the software can provide alternate views into the same knowledge base.

The intelligent-assistants component of the OIA includes two intelligent assistants to aid in construction and evaluation of semantic models. The Vehicle Definition Assistant (VDA) helps the user in quickly constructing a model of a conceptual launch vehicle by defining its components, subsystems, systems, and hierarchical relationships among them. The Operations Definition Assistant (ODA) helps the user define and assess launch-vehicle-processing flow, time lines, and requirements.

The knowledge base contains an extensive, expandable collection of data on launch vehicles and components thereof. It also contains data on processing and resources pertinent to launch vehicles and their components. The knowledge base is contained in a common template library and individual project libraries. The user gains access to the vehicle data via the VDA and to the processing and resource data via the ODA.

The utilities component of the OIA includes three major software utilities that support the intelligent assistants. One utility is the Assessment Tool, which prepares a schedule of the vehicle-processing flow for comparison with other vehicle flows. Another utility is the Reporting Tool, which generates time lines, resource histograms, and other reports in different formats to identify and display the effects on schedules and resources. The Reporting Tool is also used to format and transmit the output

of the Assessment Tool for printing or for use in other computer programs. The third utility is the Model Management utility, which provides a link between the intelligent assistants and the internal sources of data. While functioning automatically in the background, this utility

also enables the storage and retrieval of models and provides access to both internal and external sources of data.

This work was done by John J. Cwikinski, Robert B. Sieck, Jr., and Roy C. Tarpe, Jr., of McDonnell Douglas Corp. for **Kennedy Space Center**.

Further information is contained in a TSP [see page 1].

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 1]. Refer to KSC-11836.

National Aeronautics and
Space Administration



END

06/12/98